Precipitation and Runoff Characteristics, Queen Charlotte Islands

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FISH/FORESTRY INTERACTION PROGRAM

This study was undertaken as part of the Fish/Forestry Interaction Program (FFIP), a multi-disciplinary research study initiated in 1981. The program was started following a series of major winter storms in 1978 that triggered landslides over much of the Queen Charlotte Islands forest land base. Originating on steep slopes, many slides deposited tonnes of debris in streams and on valley flats. The events raised private and public concerns over logging practices on the Islands and prompted the establishment of the 5-year program. Overall objectives of FFIP were:

- to study the extent and severity of mass wasting and to assess its impacts on fish habitat and forest sites.
- to investigate the feasibility of rehabilitating stream and forest sites damaged by landslides.
- to assess alternative silvicultural treatments for maintaining the improving slope stability.
- to investigate the feasibility and success of using alternative logging methods, including skylines and helicopters, and by logging planning to reduce logging-related failures.

The program is jointly funded by direct appropriations from the Canada Department of Fisheries and Oceans, the B.C. Ministry of Forests (Research Branch), and the B.C. Ministry of Environment (Fisheries Branch). Participating agencies include Forestry Canada (Pacific Forestry Centre), and the Forest Engineering Research Institute of Canada (FERIC), Vancouver, B.C.

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Precipitation and Runoff Characteristics, Queen Charlotte Islands

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ABSTRACT

The report provides a regional evaluation of precipitation and streamflow on the Queen Charlotte Islands. All available hydrometeorological data were consolidated from federal and provincial government agencies. The Queen Charlotte Islands were stratified into regions with homogeneous precipitation regimes. This regionalization was then used to develop relationships between monthly runoff and monthly precipitation. Frequency analyses for large magnitude rainstorms and runoff events are presented and used to determine the relationship between storm runoff and storm precipitation. For design purposes, where no data exists for storm precipitation characterisitics, a statistically significant relationship for estimating mean annual peak flows, based upon watershed properties and mean annual precipitation, is presented. Standard hydrology analyses are used. The relationships presented in the paper are statistically significant. However, limitation noted in the report indicated that long-term hydrometeorological data must be collected for the Queen Charlotte Islands so that more reliable precipitation-runoff relationships and more confident return period estimates can be developed.

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1 INTRODUCTION

Many studies over the past decade have dealt with natural resource issues on the Queen Charlotte Islands. These studies have encompassed fisheries, forestry, mining, and recreation. In all of them, regional and local climate has been discussed in various degrees of detail. Precipitation and stream runoff data have been required in Fish/Forestry Interaction Program (FFIP) reports (Tripp 1986; Hogan 1986; Karanka 1986; Roberts 1987), and in B.C. Forest Service (BCFS) reports dealing with landslides (Wilford and Schwab 1982; Schwab 1983) and biogeoclimatic zone classification (Banner *et al.* 1984). In addition, mining development applications routinely require an evaluation of precipitation and runoff data.

Although these studies identify the importance of climate to natural resource planning on the Queen Charlotte Islands, none has included a complete review of local and regional hydrometeorology. The one exception is an early report by Williams (1968). However, at that time only 2 years of data for a single west coast climate station (Tasu Sound) were available and of that no continously recorded streamflow data were included. This seriously limits the usefulness of Williams' work to resolve contemporary issues.

Several ongoing and proposed studies on the Queen Charlotte Islands require hydrometeorological information. These include BCFS investigations of landslides[1] and fluvial sediment distributions (FFIP), and proposed studies of the temporal adjustment of stream channels to abnormally large sediment inputs by landslides. Furthermore, hydrometeorological information forms an important supplement to an ongoing study[2] which evaluates the meteorological antecedent conditions associated with landslides. This work logically requires a review of regional hydrometeorology. Also, the Forest Service is often requested by internal and external organizations for data previously compiled for various projects. Response to these requests has been difficult because of the diverse nature of the data collected for each project.

The objectives of this report are: 1) to consolidate available precipitation and streamflow data; and 2) to conduct basic data analyses to satisfy the types of questions most frequently asked about the climate of the Queen Charlotte Islands. The questions usually asked are: What is the relationship between precipitation and runoff in the Queen Charlotte Islands? What is the relationship between precipitation and geographic location in the Queen Charlotte Islands (pattern of spatial precipitation variability)? What is the relationship between geographic location and runoff in the Queen Charlotte Islands? In response to these questions, the following analyses were undertaken:

- development of relationships between precipitation events and storm runoff amounts;
- regionalization of precipitation and runoff regimes;
- estimation of the influence of elevation on precipitation amounts;
- frequency analyses for extreme precipitation and stream flood events; and
- development of a relationship between watershed and streamflow characteristics.

This report evaluates the suitability of the currently available precipitation and runoff data to address common information requirements. It also identifies the limitations placed on the analyses due to data quality and quantity problems. These deficiencies are identified to show where more monitoring is required and to place confidence limits on the analyses presented here.

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[1] Schwab, J.W. 1985. Historical Documentation of Mass Wasting, North Coastal B.C. EP782.07. B.C. Min. For., Victoria, B.C.

[2] Hogan, D.L. and J.W. Schwab. 1986. Meteorological conditions associated with hillslope failures on the Queen Charlotte Islands. EP782.09. B.C. Min. For., Victoria, B.C.

2 DATA SOURCES AND METHODS

2.1 Data Sources

Long-term precipitation records (30-year normals) were obtained from the Canadian Atmospheric Environment Service (AES). Short-term records (4 years of daily values and simulated 30-year normals) were obtained from the British Columbia Ministry of Environment, Resource Analysis Branch (RAB). The location of each station is shown in Figure 1. A list of selected stations, record lengths, and the reliability of each data set are presented and discussed in Appendix 1. Also, continuous precipitation records of less than 2 years in duration were collected by field staff during the Fish/Forestry Interaction Program (FFIP)[3] and obtained for three watersheds. Their reliability is considered in Section 5. Standard tipping bucket rain gauges and mechanical chart event recorders were used at the FFIP sites. Site characteristics at these locations complied with correct site conditions as outlined by the provincial Air Studies Branch (ASB) and the federal AES.

Long-term streamflow records were obtained from the Water Survey of Canada (WSC). Only three stations have more than 2 years of records available for the Queen Charlotte Islands (Table A2.2). Continuous streamflow records were also obtained for three sites by FFIP personnel. These records, which are between 1 and 2 years in length, are not completely reliable (Section 5) and had to be carefully reviewed before the data were accepted and used in this study. The FFIP streamflow gauging stations were located in pool sections of the channel, and immediately upstream of stable riffles. Each site was equipped with a Stevens stage recorder and stilling well. Stream gauging was conducted on numerous occasions (more than 12 times at each station) to construct and maintain the stage-discharge rating curve. A Price Type A or OTT meter was used to measure flow velocity. All field and analytical procedures followed were in accordance with methods given by Church and Kellerhals (1970). All stage records were digitized by computer. Daily mean, maximum, and minimum discharge records, in addition to the stage recorder chart, are on file at the B.C. Ministry of Forests Prince Rupert Regional Office in Smithers.

2.2 Frequency Analysis

Frequency analyses were performed on the long-term AES precipitation and WSC flow data. All analyses were done by the relevant government agency and standard techniques were used.

2.2.1 Precipitation

Maximum annual 1-day, 2-day and 3-day precipitation totals for each AES station on the Queen Charlotte Islands were collected from the published AES data summaries. The AES provided the detailed frequency analysis tables (Table A2.1).

2.2.2 Streamflow

Daily, monthly, and annual streamflow data for each station on the Queen Charlotte Islands were collected from the published WSC data summaries. Instantaneous and daily maximums for each year are compiled and entered into files on the B.C. Ministry of Environment computer system[4]. The Ministry of Environment program provides frequency analysis using four distributions:

1. three-parameter log-normal distribution, fitted by the method of maximum likelihood;
2. Gumbel distribution, method of moments;
3. Pearson Type III distribution, method of moments; and
4. Log-Pearson Type III distribution, method of moments.

[3] Data collected by L. Beaven, D. Boulion, and F. Noone.
[4] All computer work was conducted by R. Wyman, B.C. Ministry of Environment, Victoria, B.C.

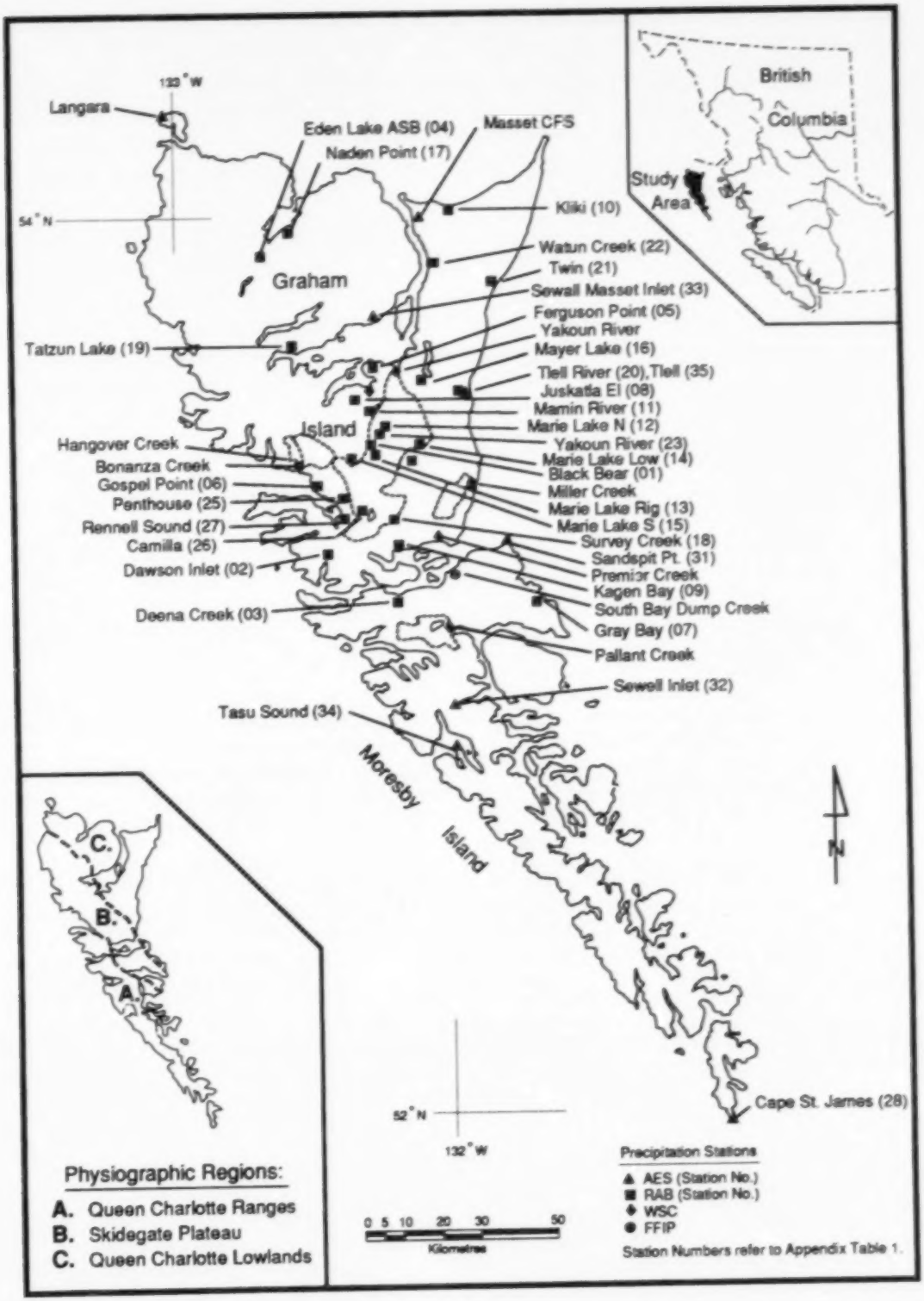

FIGURE 1. Location of hydrometeorological stations on the Queen Charlotte Islands.

The final choice of the distribution use is left to the discretion of the individuals requesting the data analysis.

The "unbiased" or Cunnane formula for plotting positions is used; but, for each data set, plotting positions are provided using the Weibull, and Weibull and Hazen formulas (Appendix 2). The program provides standard errors and 95% confidence limits for all but the Gumbel distribution.

The following procedure was used to decide on the "best" distribution for each application of the program:

- The statistics for the Kolmogorov-Smirnov (K-S) test for goodness of fit, provided by the program for each distribution, were analyzed. The program documentation provides guidelines for using these statistics.
- The standard errors for the 20-year estimate were compared.
- The data points and the four fitted distributions were plotted, and the fit of the distributions to the data was qualitatively examined. Log-Gumbel paper was used for plotting and the graphs are included in Appendix 2 (Figure A2.2).

2.3 Calculation of Precipitation and Runoff Relations

The general relationship between precipitation and runoff was evaluated by reviewing RAB, AES, and WSC data. Precipitation data were taken either from the closest weather station to the corresponding watershed, or from the average of a number of stations. The relationships developed are based on regression analyses incorporating monthly precipitation and monthly runoff (mm) totals for Pallant Creek and Yakoun River.

All precipitation-runoff events were identified and selected from Hangover, Miller, and South Bay Dump creeks (FFIP). The corresponding time periods were obtained for the Yakoun River, Pallant Creek, and Premier Creek (WSC).

Discharge hydrographs were plotted for each event and stream. Hydrograph separation was accomplished by projecting the pre-storm baseflow under the peak and drawing a line from the point directly beneath the peak flow to a point on the recession limb N days after the peak, where N (days) = $A^{0.2}$ (mi^2), according to Dunne and Leopold (1978). Stormflow volumes were calculated by planimetering the area beneath the curve, as shown in Figure 2. Event timing was based on the lag time between maximum precipitation and peak streamflow.

Precipitation intensity was calculated as the amount of storm precipitation divided by the storm duration. The calculation of three different intensity values were required because of record variations between stations: "average intensity" refers to the mean daily precipitation for duration of the storm; the "maximum 24-hour intensity" refers to the single day with the greatest amount of precipitation (all AES stations); and "maximum intensity" for all FFIP stations refers to the steepest segment of the hourly cumulative precipitation chart.

Antecedent moisture conditions were defined according to the precipitation characterization methodology of Kohler and Linsley (1951, in Linsley *et al.* 1975). This technique assumes that soil moisture decreases logarithmically with time during periods of no precipitation,

$$I_t = I_o K^t$$

where I_o is the initial value of the antecedent-precipitation index, I_t is the reduced value t days later, and K is a recession factor ranging normally between 0.85 and 0.98. The available water capacity multiplied by the depth of soil profile provides the first estimate of I_o (Dunne and Leopold1978). Soils considered typical for the study area are Ferro-humic podzols 1 m deep (Smith *et al.* 1986). The k value used was 0.9. The I_o was calculated as 100 mm, which assumes soils are of a sandy loam texture. The 10-day period before each storm was considered.

Storm analyses were conducted in a consistent manner. Only rainfall that produced the runoff was selected. Small showers occurring after the hydrograph had started to recede were not included. The

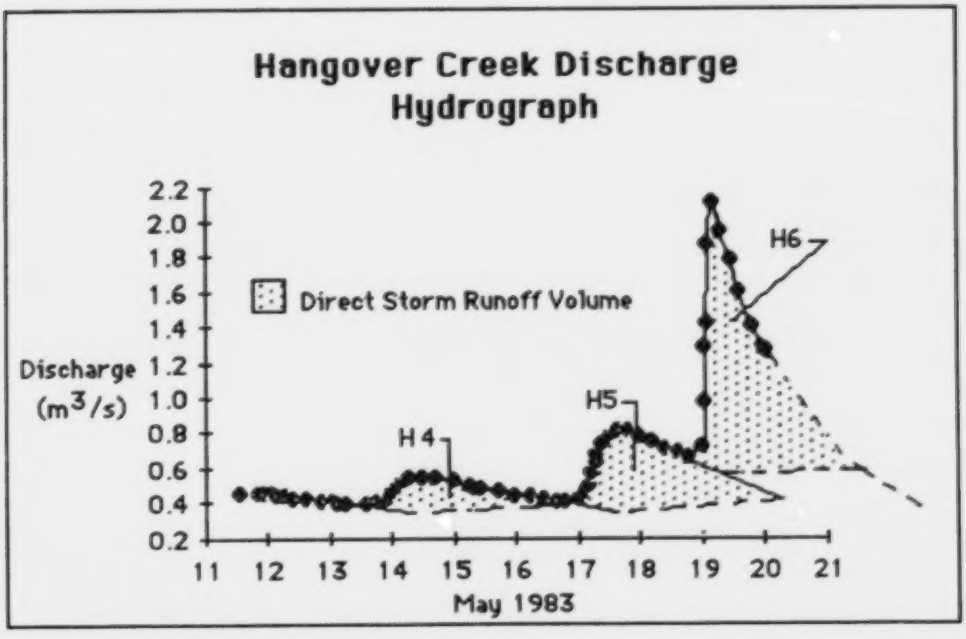

FIGURE 2. Example of method used for hydrograph separation.

procedure of selecting WSC records that corresponded to the same runoff event measured at FFIP sites caused minor analytical problems. These resulted from a difference in storm timing at the WSC stations: because of different storm track directions, the same storm would arrive at the WSC site either before or after its arrival at the FFIP sites. In these cases, precipitation and runoff from slightly different time periods would be analyzed. Also, the storm intensity would often change between the FFIP and WSC sites, so that in some cases rather small events were included in the analyses.

2.4 Peak Flow Estimation Based on Precipitation and Watershed Characteristics

Two methods are used to estimate streamflow in ungauged watersheds. First, a simple graph relating watershed area[5] and mean annual maximum instantaneous discharge (Benson 1962) was plotted. Streamflow values were obtained from the frequency analysis data conducted by the B.C. Ministry of Environment.

Hangover and Bonanza creeks were included to extend the range of watershed sizes (drainage basin areas of 20.2 and 45.2 km^2, respectively). Data for these watersheds were derived from Hogan (1985). The mean annual maximum instantaneous discharge is used and refers to the flow corresponding to a recurrence interval of 2.33 years[6] assumed to be equal to the bankfull discharge based on morphological evidence.

Second, a multiple regression model was developed relating mean annual maximum instantaneous discharge to mean annual precipitation, basin relief, elevational bands (proportion of basin below 150 m, between 150 m and 1000 m and above 1000 m) and area occupied by lake. Precipitation values were estimated from geographical precipitation zones in Figure 8. Basin characteristics were obtained from 1:50 000 topographic maps for the large basins (Yakoun and Pallant) and from air photographs for the smaller watersheds. Areas were measured with a digital planimeter. The elevation limits selected were based on biogeoclimatic zones (Banner *et al.* 1984).

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[5] Watershed areas were obtained from WSC records with the exception of Premier Creek which was determined from 1:20000 air photographs.

[6] Record length of 2 years is insufficient for frequency analysis (a minimum of 10 years is required).

3 REGIONAL PRECIPITATION

The Queen Charlotte Islands are characterized by a humid, temperate climate with mild winters and cool summers. Williams (1968) presents a relatively thorough review of the climate patterns and Karanka (1986) provides an assessment of long-term temporal climatic variability. Spatial patterns of precipitation only are considered in the present paper.

The AES operates eight weather stations on the islands. These are not representatively distributed: only one station was located on the west coast (Tasu, which was discontinued in 1984). The AES records indicate that the mean annual precipitation varies from approximately 1200 mm on the northeast coast of Graham Island to over 4200 mm on the west coast. Higher elevations on the west coast probably receive far in excess of this value (Williams 1968). Snowfall amounts appear to be insignificant when compared to annual rainfall amounts (1% of the mean annual precipitation at Cape St. James and 5% at the other stations), although no snow gauges or courses are operated on the islands.

3.1 Synoptic Patterns

The climate of all mid-latitude locations is characterized as a zone of prevailing westerly winds, with migratory high and low pressure systems moving generally west to east from regions of formation to their eventual dissipation. The general synoptic climatology of the Pacific Northwest has been documented by Maunder (1968), Suckling (1977), Zishka and Smith (1980), and Yarnal (1983).

Cyclonic storms are particularly important because their frequencies are related to the general variability of inclement weather at a site and are important to the seasonal and annual variation in precipitation. Patterns of cyclone development, movement and dissipation have been detailed by Klein (1957) and Reitan (1974). Lewis and Moran (1985) have discussed the synoptic setting of 125 severe storms which occurred off the west coast of British Columbia. An example of their data is presented in Figure 3; this depicts the atmospheric conditions during an early winter storm in 1978. The heavy rainfall received on the islands during this storm was due to the passage of a strong frontal zone ahead of a deep low pressure cell centred over western Alaska (Schaefer 1979a and b).

Figure 4 shows 25-year composite storm track summaries for October, November, and December. Clearly, severe winter storms are a relatively common occurrence in areas adjacent to and north of the Queen Charlotte Islands.

3.2 Precipitation and Topography

Precipitation gradients are highly influenced by orographic uplifting across the Insular Mountains (Figure 1). Mean annual precipitation reaches 4500 mm per year within 20 km of the windward outer coast and diminishes gradually across the leeward slope of the Skidegate Plateau (Karanka 1986). The leeward coastal plain is relatively flat and usually does not exceed 150 m in elevation. Annual precipitation in the eastern areas varies from 1200 to 1500 mm.

No clear pattern emerges between mean annual precipitation and elevation when all AES and RAB stations are compared (Figure 5). Although precipitation usually increases with elevation, there is too much variability to allow a general relationship to be developed. This variability is likely a result of the inclusion of stations on both the leeward and windward sides of the north-south trending mountain range of the Queen Charlottes. The scatter of certain points is possibly also due to operational problems associated with high-elevation stations (e.g., wind exposure and snow accumulations).

Two locations with multiple rain gauges were considered so that the importance of elevation to precipitation amounts within similar areas could be evaluated. The stations in the Marie Lake area and immediate vicinity were operated for between 4 and 8 years by the RAB. These stations were located in the Skidegate Plateau Region (see Figure 1) and consisted of a series of 15 precipitation gauges. The stations

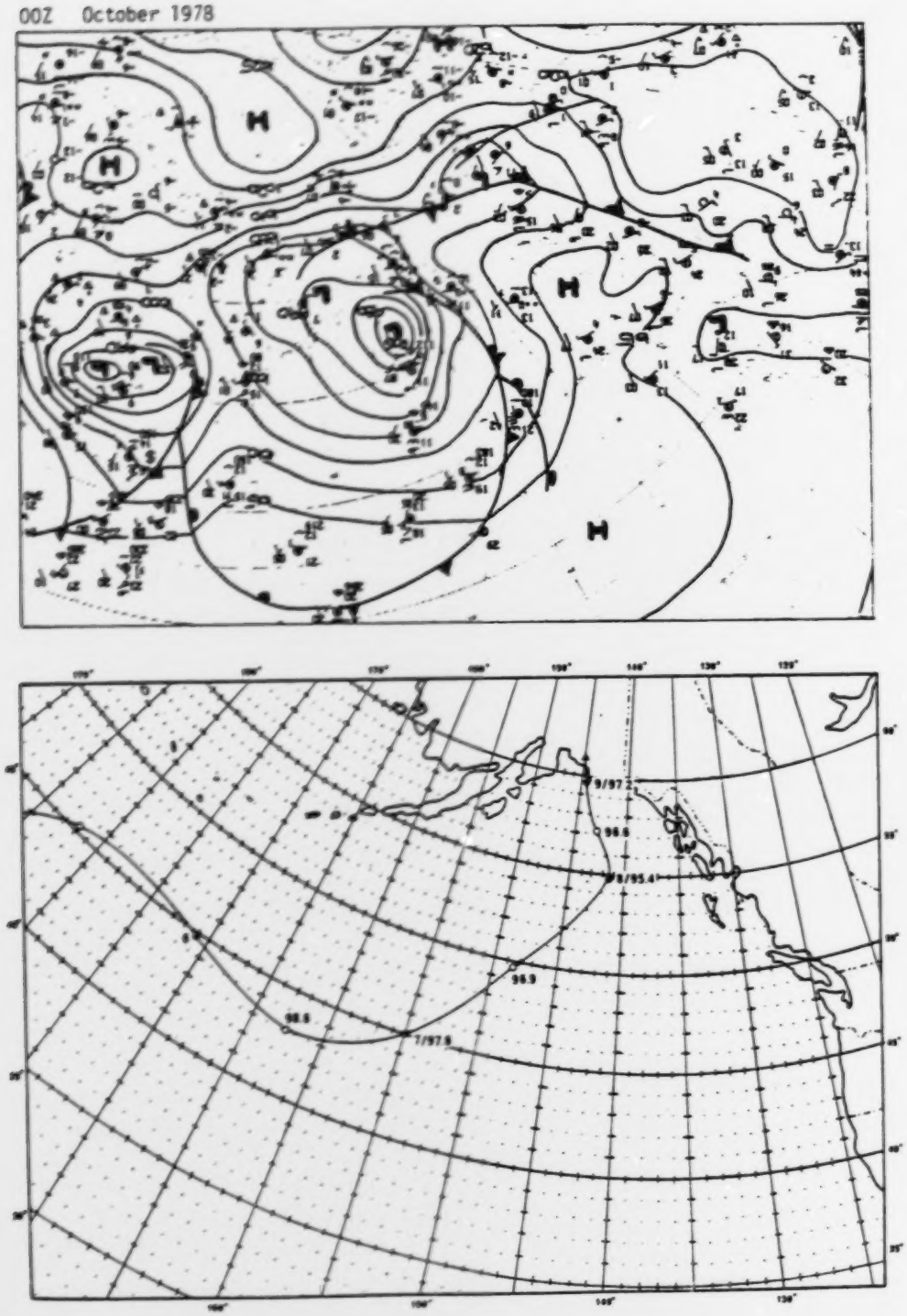


FIGURE 3. Surface synoptic chart for October 30, 1978, storm (from Lewis and Moran, 1985).

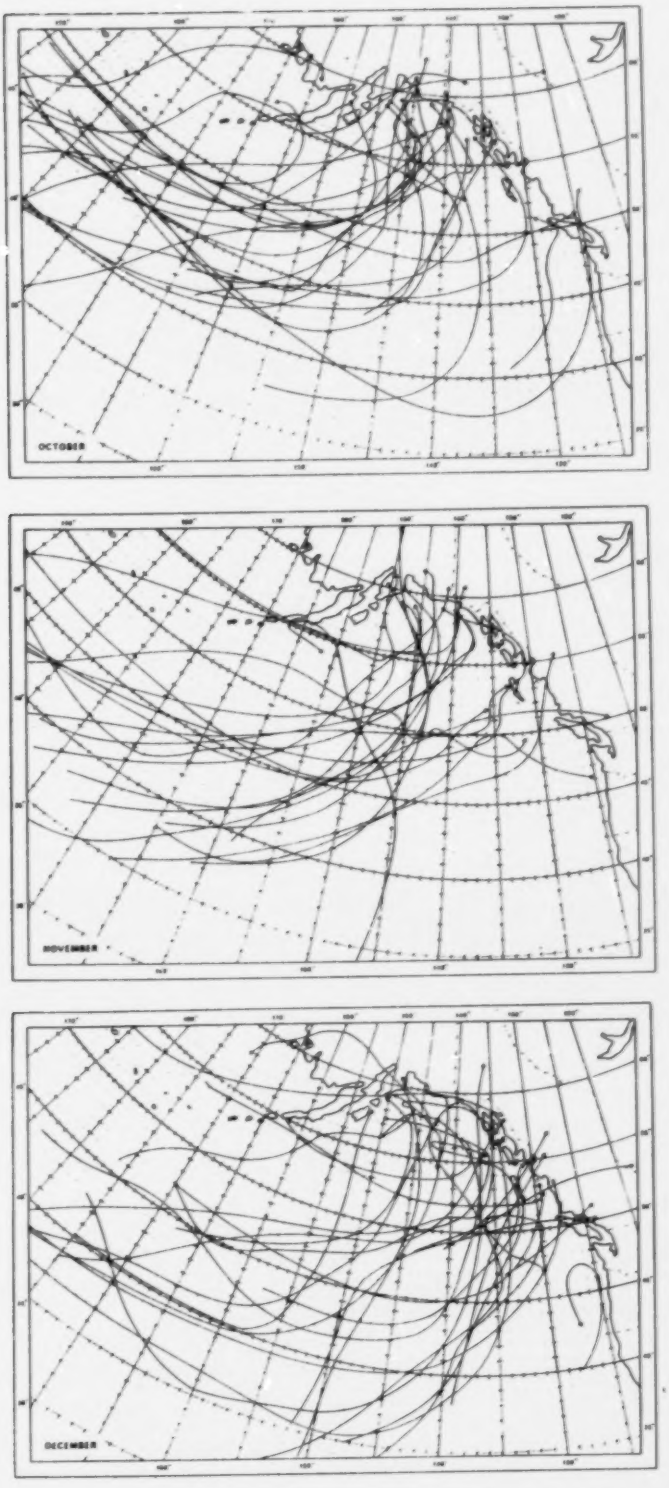


FIGURE 4. Composite storm track summary for the months of October, November, and December, 1957 - 1983 (from Lewis and Moran, 1985).

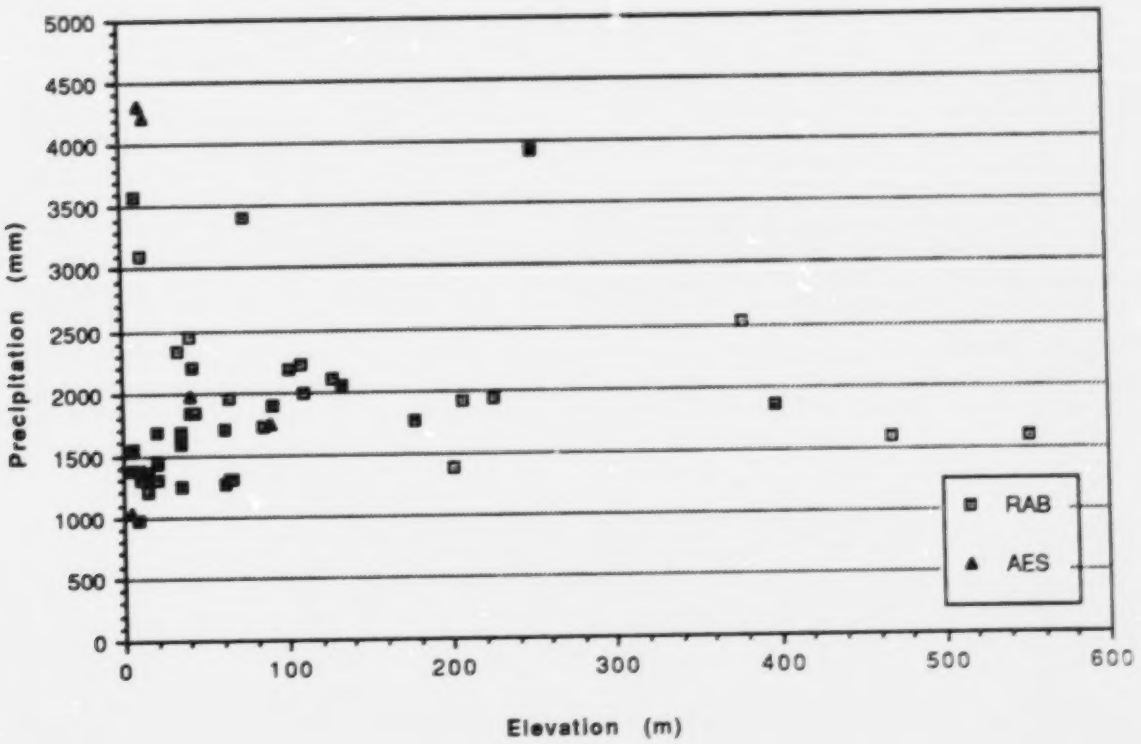


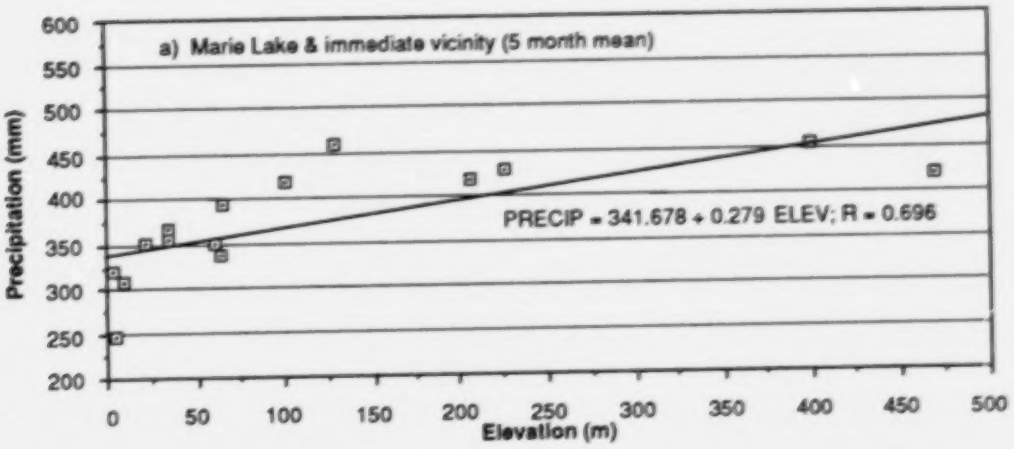
FIGURE 5. Mean annual precipitation (30-year normals) at 8 AES and 44 RAB stations. Note that the RAB values are estimates of the long-term mean annual precipitation as calculated by that agency.

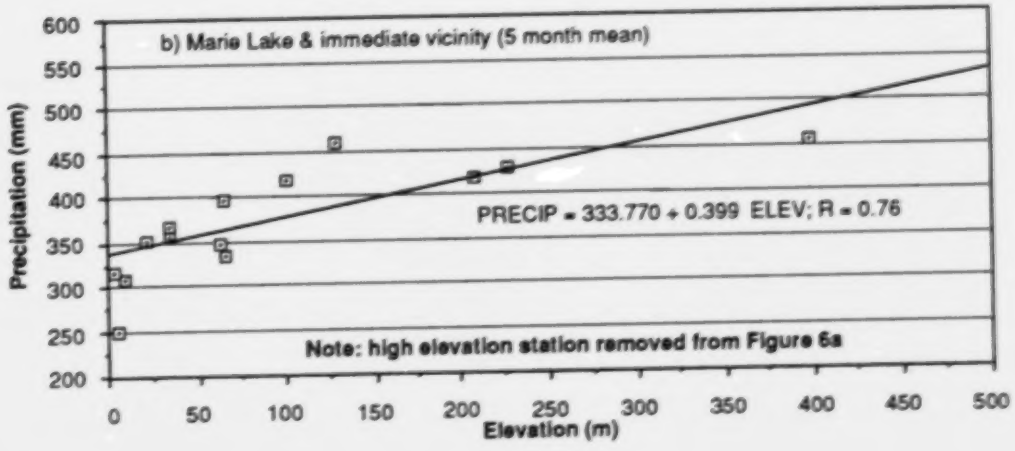
ranged in elevation from near sea level to approximately 470 m above sea level. There is speculation that the highest station suffers from exposure problems during high winds (B. Marsh, pers. comm., Air Studies Branch ASB), which leads to lower than actual estimates of precipitation for this elevation. The South Bay Dump Creek network, installed by FFIP personnel, consisted of six gauges and was operated from May 1983 until March 1984.

The relationships between precipitation and elevation (Figure 6) are as follows:

	South Bay Dump:	PRECIP	=	1108.024 + 0.321 ELEV (n = 6, r = 0.830)
	Marie Lake:	PRECIP	=	341.678 + 0.279 ELEV (n = 15, r = 0.696)
or	Marie Lake:	PRECIP	=	337.770 + 0.399 ELEV (n = 14, r = 0.760, excludes high-elevation station)
where:		PRECIP	=	total precipitation (mm) for period of record
		ELEV	=	Elevation (m)

The graphs in Figure 6 indicate that elevation exerts a significant influence on precipitation amounts (at 95% confidence level). Precipitation increases by approximately 30-40 mm for each 100-m increase in elevation for the given records. Only the slope of the regression line is important because the record lengths do not correspond to a given time period (e.g., month, season, year). The intercept reflects the particular record length (5 months for the Marie Lake and vicinity stations, and 6 months for the South Bay Dump Creek stations).





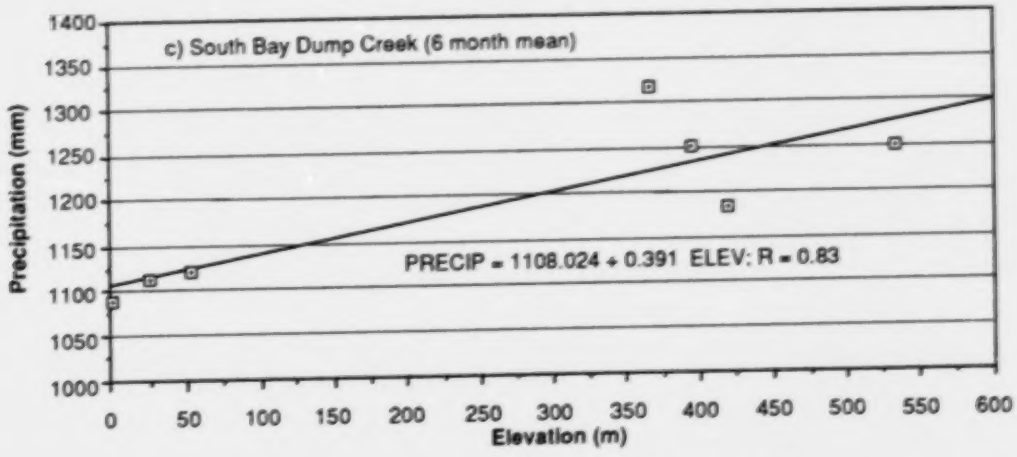


FIGURE 6. Precipitation-elevation relationships for Marie Lake (6a and 6b) and South Bay Dump Creeks (6c).

3.3 Precipitation Regionalization

Precipitation and runoff are a function of local weather and, over the long term, of climatic conditions. Precipitation is a difficult factor to assess because it is highly variable over short distances, particularly in areas of diverse topography such as the Queen Charlotte Islands. The variable spatial and seasonal distributions are shown in Figure 7, which is a plot of cumulative mean monthly precipitation values for several AES and ASB stations. The highest precipitation areas (greater than 3000 mm per year) are on the west and north coasts of Moresby Island. The areas with more modest amounts (approximately 2400-3000 mm per year) are on the west coast of Graham Island, and the areas with the lowest amounts (less than 2000 mm per year) are on the north and east coasts of Graham Island. The shape of curves in Figure 7 indicates that a low proportion of the total annual precipitation falls between May and August, while a large proportion is received from October through April.

The spatial pattern of annual precipitation, based on 8 AES and 27 RAB stations, is summarized in Figure 8 and presented in detail in Appendix 1. Although the delimited zones correspond well to regional physiography (Figure 1), there are several points that must be noted. First, the exact boundary of each zone is impossible to determine because the zones are based on relatively few values (35 stations spaced unevenly over 10000 km^2). Second, the zones are discontinuous because they correspond to the 95% confidence limits placed around the mean annual precipitation value calculated for each zone. That is, the zones represented ranges derived from the available data only; clearly there are sites with precipitation levels between the delineated zones, but these are not represented in the data base. No attempt has been made to interpolate between the zones delineated on Figure 8. The third point to note is that the relatively few stations within each zone make it impossible to determine significant relationships between precipitation and geographic location (proximity to the ocean and mountains). However, when all stations are considered together, the best model combining geographic elements is:

	ANN PRECIP	=	1342.341 LONG - 1327.320 LAT - 104449.480
where:	LONG	=	longitude, in degrees
	LAT	=	latitude, in degrees
	ANN PRECIP	=	mean annual precipitation, in mm

This model accounts for 44% of the variation in precipitation (significant at $\alpha = 0.05$, df = 32). A detailed discussion of the work is contained in Appendix 1.

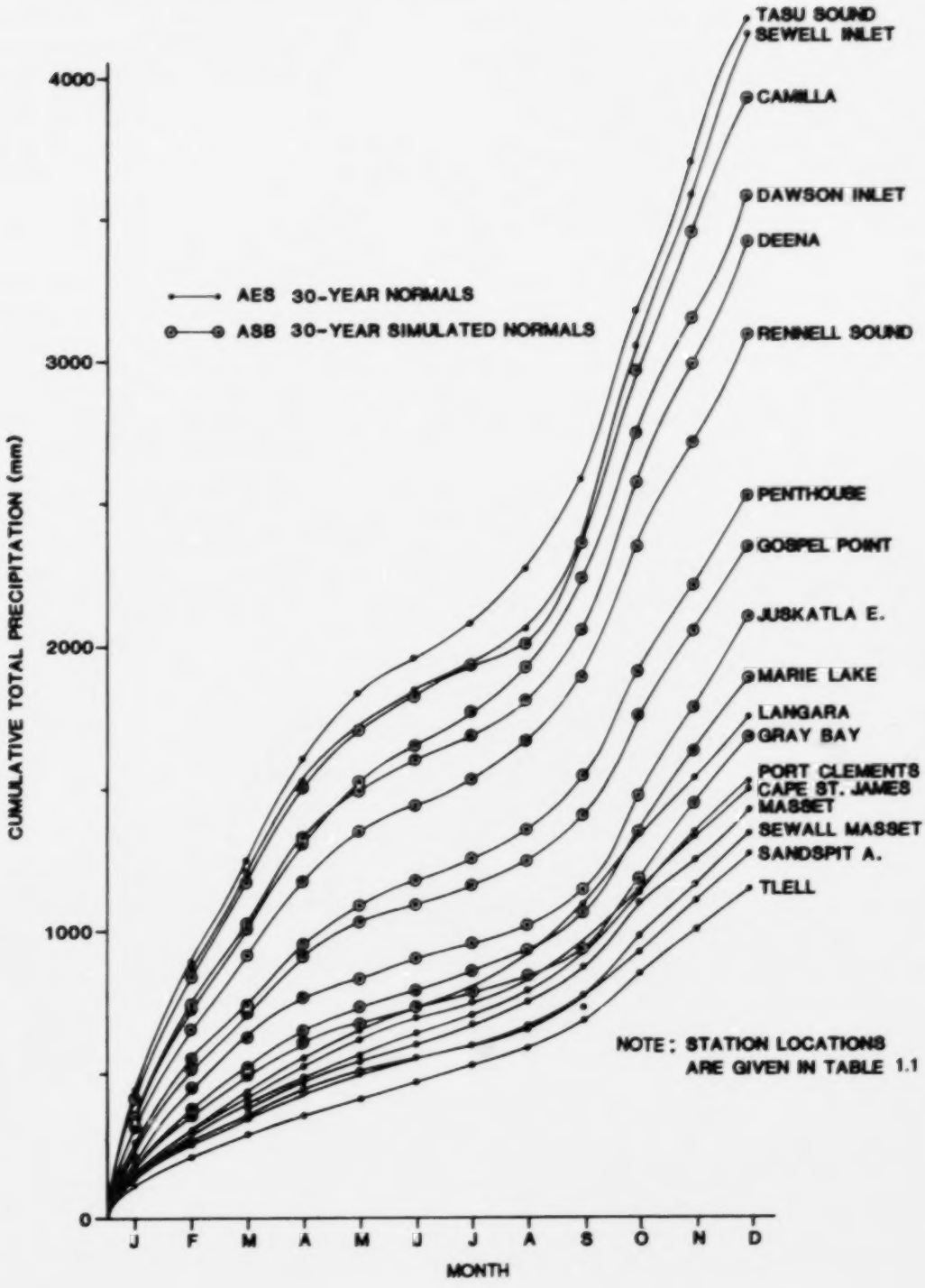


FIGURE 7. Cumulative precipitation plots for selected AES and RAB climate stations.

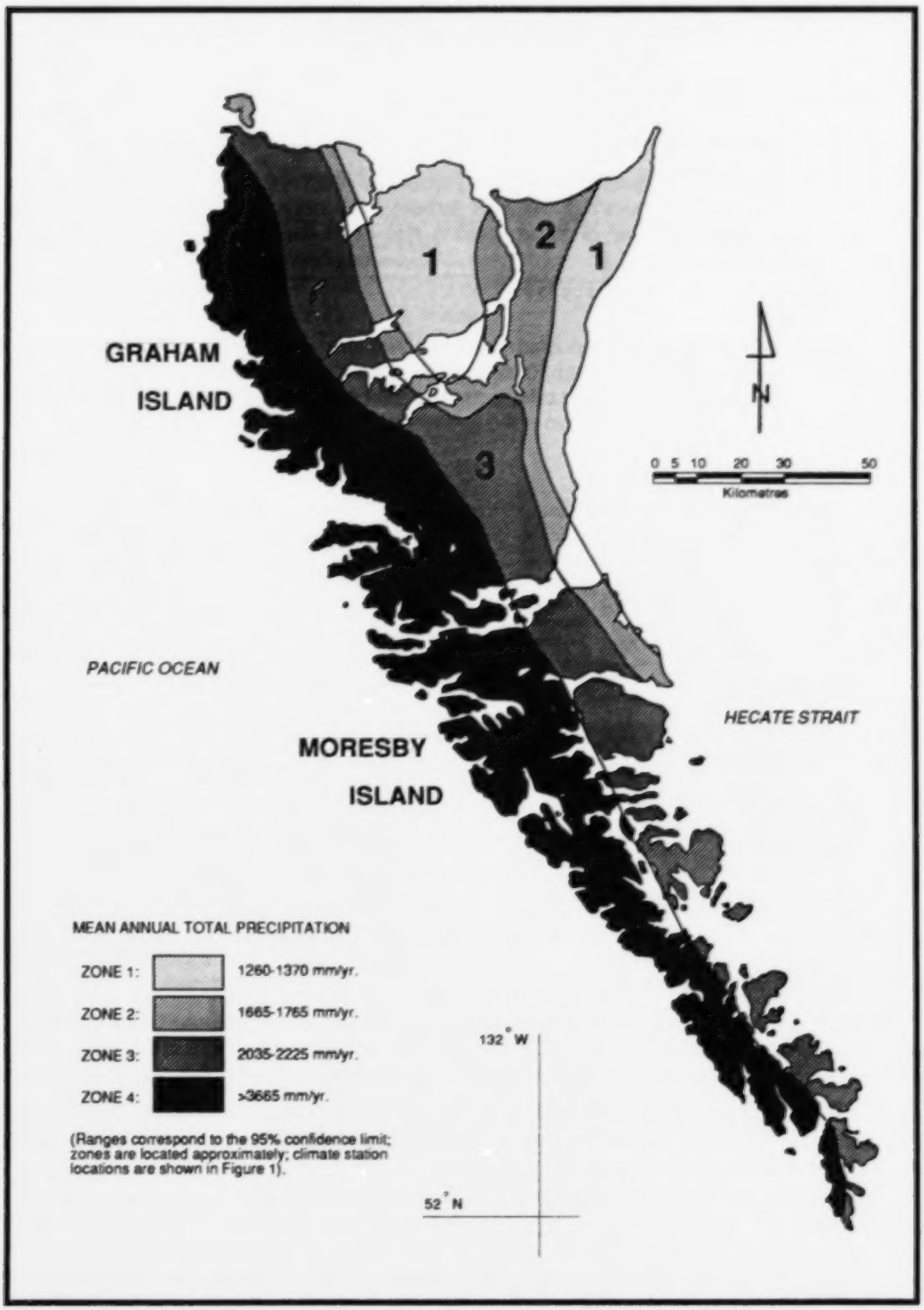


FIGURE 8. Spatial variation of precipitation in the Queen Charlotte Islands.

4 LONG-TERM DATA

4.1 Frequency Analysis

4.1.1. Precipitation

The results of AES frequency analysis on precipitation data are summarized in Figure 9. Detailed results are included in Appendix 2. All AES stations have been considered in these analyses for completeness. Because three of these stations had been discontinued by 1976, they were not considered in Section 3.

4.1.2 Streamflow

Frequency analyses were conducted on the data sets for the three available stations, with the use of the MOE frequency analysis program. Table 1 summarizes the results of the frequency analysis, giving 5-, 10-, and 20-year peak flows and other summary data for the three stations (Yakoun, Palland, and Premier creeks). A detailed tabulation of the frequency analysis is presented in Appendix 2.

TABLE 1. Streamflow frequency analysis summary

Station drainage area	Years record	Mean annual discharge runoff	Instantaneous max. (cm) 5 yr 10 yr 20 yr	Daily max. (cm) 5 yr 10 yr 20 yr	Ratio Instantaneous/daily 5 yr 10 yr 20 yr
Yakoun River 080A002 447 km²	24	33 cm 0.07 mm	437 525 617	363 445 430	1.20 1.18 1.43
Pallant Creek 080B002 76.7 km²	17	9.5 cm 0.111 mm	99.4 119.3 140.1	65.7 80.3 96.9	1.51 1.49 1.45
Premier Creek 080A003 0.8 km²	14	0.019 cm 0.024 mm	0.439 0.521 0.607	0.262 0.314 0.370	1.68 1.66 1.64

4.2 Precipitation-Runoff Relationship

The Water Survey of Canada has operated six hydrometric stations in the Queen Charlotte Islands, three of which have been operating for more than 10 years. These stations are located on the Yakoun River near Port Clements, on Pallant Creek downstream of its confluence with Mosquito Creek, and on Premier Creek.

The Yakoun watershed has a drainage basin of 477 km² and includes Yakoun Lake, which covers approximately 2% of the drainage basin. This drainage basin lies within the Skidegate Plateau physiographic zone and has a median elevation of approximately 200 m.

The Pallant Creek watershed, lying within the Queen Charlotte Ranges physiographic unit, covers an area of 76.7 km² and includes a lake which accounts for approximately 7% of its area. The median elevation of the Pallant Creek watershed is about 300 m. The Premier Creek basin is estimated to be 0.8 km² and lies between Yakoun River and Pallant Creek within the Skidegate Plateau physiographic unit. It has a median elevation of 240 m, and does not contain a lake. As most drainage basins in the Queen Charlotte Islands are small and do not contain lake systems, two of the three WSC stations are considered atypical for characterizing runoff in small watersheds that are without lakes.

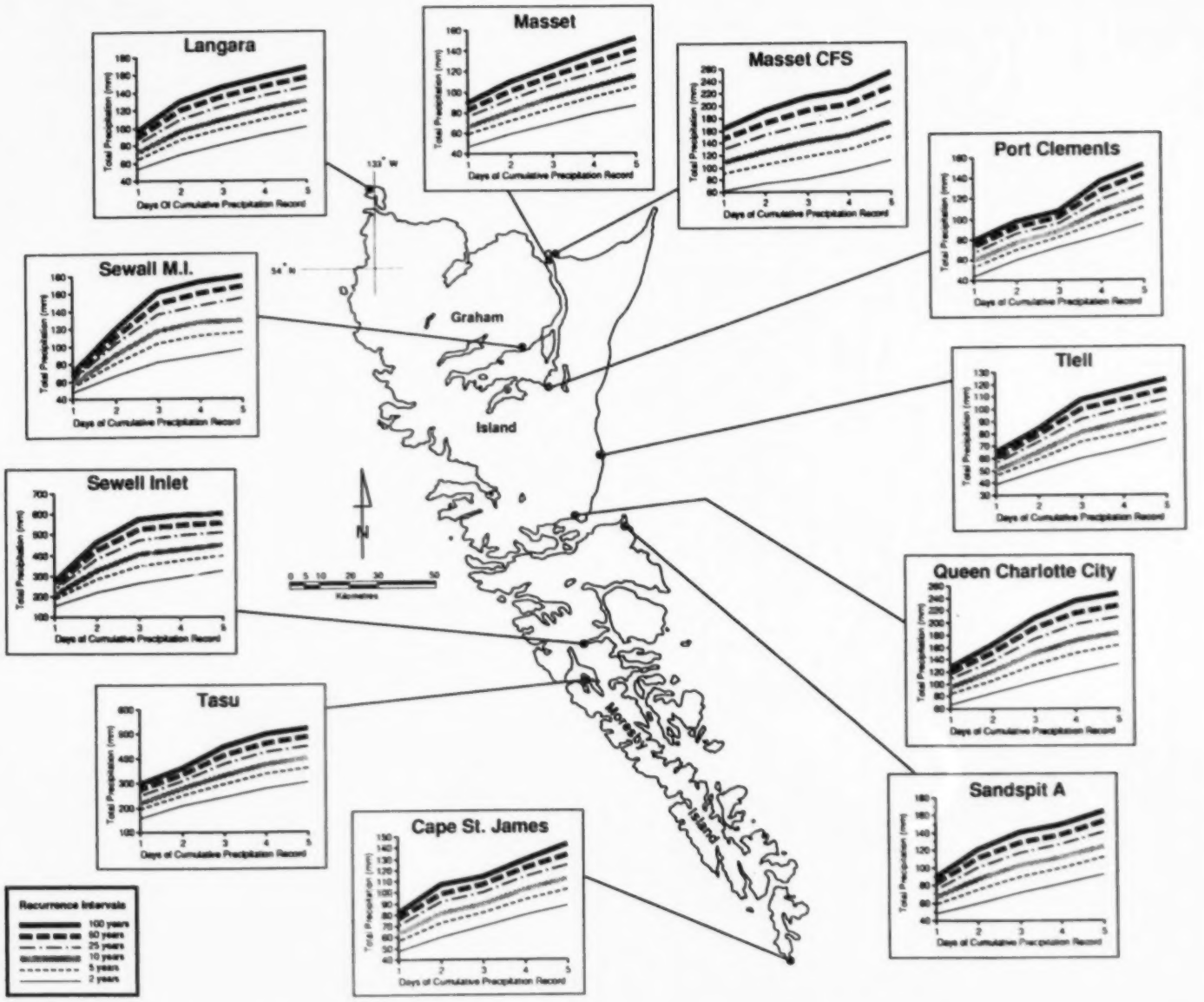


FIGURE 9. Summary of probable precipitation amounts for different recurrence intervals.

The mean monthly discharge hydrographs for the three basins are presented in Figure 10. These indicate that the greatest discharges occur between October and February with maximum mean values of 61.8, 14.2 and 0.039 $m^3 s^{-1}$ for Yakoun, Pallant, and Premier creeks, respectively. These high autumn and early winter flows are due to rain and rain-on-snow storm events. The Pallant Creek hydrograph exhibits a secondary peak in April and May, which is due to snowmelt in mountainous headwater areas (e.g., Mount Mosquito). Mean monthly unit discharges (Figure 10) indicate that Pallant Creek has greater discharge per unit area drainage basin than the Yakoun watershed. This generally agrees with the precipitation patterns for each location as discussed above.

Mean monthly runoff quantities for the Yakoun River and Pallant Creek watersheds, and the regional precipitation amounts as delineated in Figure 8, are compared in Figure 11. Leith (1980), working with five AES stations, concluded that more meteorological stations are necessary to improve parametric modelling results of Yakoun River monthly flows. Mean monthly precipitation values for zone 3 stations (2035-2225 mm/yr; see Figure 8) and zone 4 stations (≥ 3665 mm/yr) were regressed against mean monthly runoff values for Yakoun River and Pallant Creek hydrometeorological stations, respectively. Regional precipitation accounts for 88% of the variability in Yakoun runoff and 80% of the variability in Pallant runoff. Both are significant at the 95% confidence level. No significant relationship (at $\alpha = 0.05$) could be found between individual AES stations and runoff in accordance with Leith (1980), indicating that regionally averaged values are a better basis on which to estimate runoff than are individual hydrometeorological stations.

In addition to spatial differences in precipitation and runoff amounts, there are dissimilarities in other precipitation-runoff characteristics. Over the short term, there appears to be a tendency for large storms (e.g., October 31 to November 1, 1978; see Schaefer 1979a and b) to be widespread and common to all basins. The relatively low annual discharge peaks of individual streams appear to be due to localized storms. Furthermore, the relative magnitude of flood flows differs between basins. The ratio of the 10-year return period instantaneous discharge to mean annual discharge is 18, 16.5, and 46 for Yakoun River, Pallant Creek, and Premier Creek, respectively. Small watersheds without lakes respond faster and have relatively higher peak discharges compared to larger watersheds containing lakes.

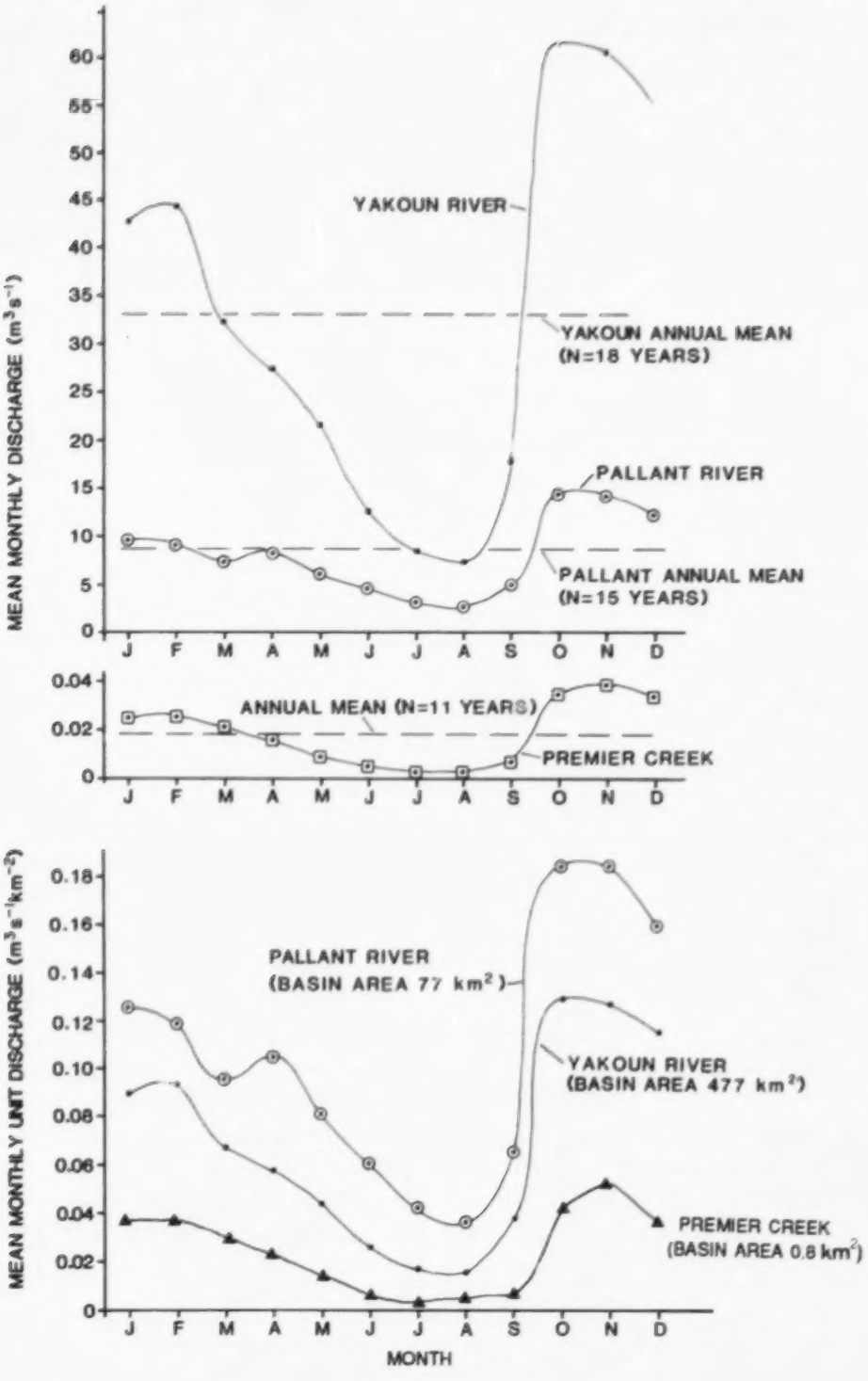


FIGURE 10. Annual mean monthly discharge and runoff for gauged Queen Charlotte Islands streams.

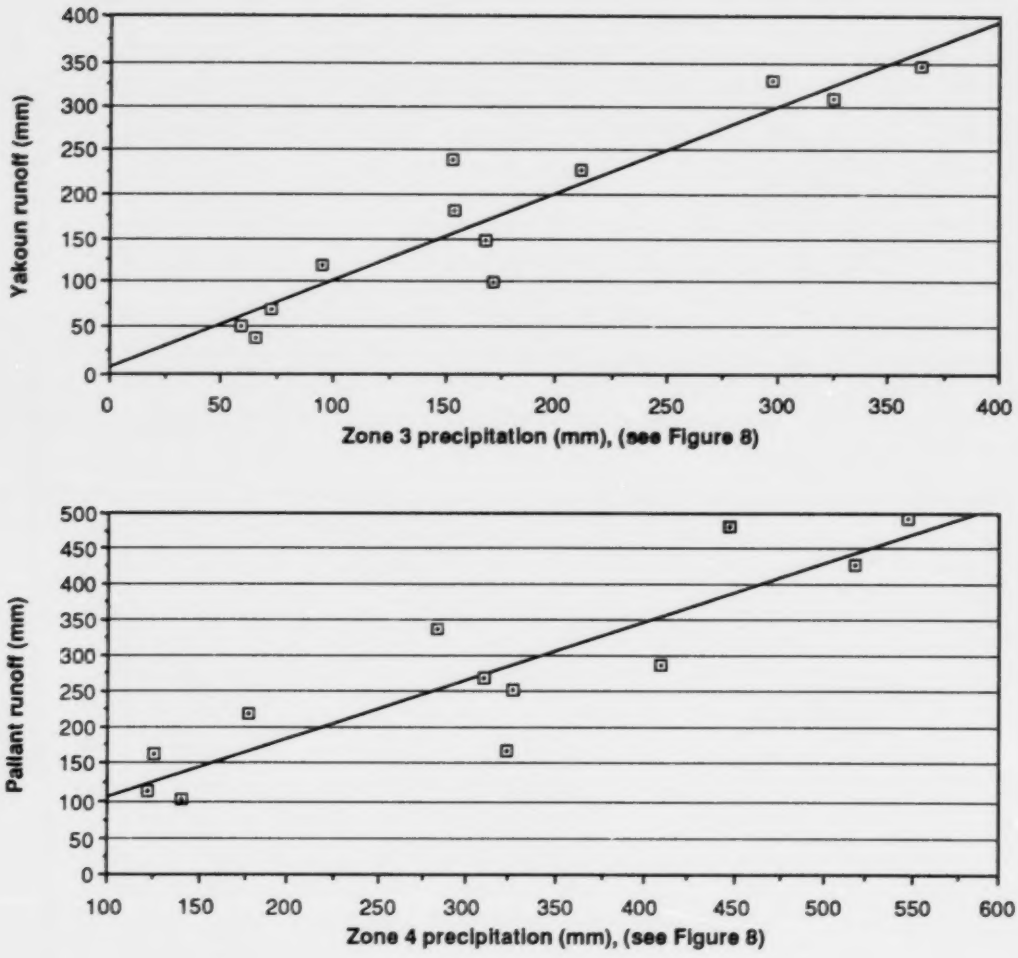


FIGURE 11. Relationship between mean monthly precipitation and runoff for two homogeneous precipitation zones considered in Figure 8.

5 SHORT-TERM DATA

Runoff is controlled primarily by variations in precipitation, although many factors influence streamflow characteristics. These range from the general climate and geology (evapotranspiration and subsurface water) of an area, to specific watershed characteristics such as surface retention and infiltration rates. The quantity of runoff from a storm depends on both the moisture conditions of the watershed at the onset of the storm and the storm characteristics (precipitation amount, intensity, and duration).

All precipitation-runoff events occurring between March 1983 and January 1984 were evaluated for the three WSC stations and their corresponding representative AES stations. In addition, three FFIP stations were considered because they typify small watersheds with no lake systems. Hangover Creek watershed, located in the Rennell Sound area, has a drainage basin area of 20 km^2 and receives more than 3600 mm of precipitation per year on average. The Miller Creek watershed is located on the east coast of Graham Island, has a drainage basin area of 23.5 km^2 and receives between 2000 and 2200 mm of precipitation each year (Figure 8). The South Bay Dump Creek watershed, located on the north coast of Moresby Island, is steep with a catchment area of 3.9 km^2. It receives in excess of 2000 mm of precipitation each year. The geographic location and precipitation regime of these FFIP sites are shown in Figures 1 and 8.

The streamflow hydrographs and precipitation records were plotted. Precipitation, streamflow, runoff, and event timing data were obtained from these plots and are detailed in Appendix 3 and summarized in Table 2.

5.1 Precipitation-Runoff Relationship

A multiple regression model was developed, using all storm data for all stations between the dependent variable (storm runoff) and four independent variables (antecedent moisture, storm precipitation amount, average rainfall intensity, and time of year). The independent variables were selected to characterize the storm condition preceding and during the precipitation event. The relationship between runoff and each of the individual independent variables is shown in Figure 12. The resultant model is:

$$y = 0.673x_1 + 0.106x_2 - 0.118x_3 - 0.111x_4 - 6.419$$

where: y = storm runoff (mm)

x_1 = storm precipitation (mm)

x_2 = antecedent moisture index (mm)

x_3 = maximum precipitation intensity (mm/hr)

x_4 = time index (1 = Jan. 1-7; 52 = Dec. 25-31)

This model is significant at the 95% confidence level

$$(F_{(data)}=13.96 > F_{(4.72)}=2.5).$$

The independent variables account for 44% of the variation in storm runoff.

The partial F values indicate that several of the independent variables contribute little to the significance of the model. By the procedure of elimination, the partial F ratios for antecedent moisture index and the precipitation intensities are shown to be insignificant (at $\alpha = 0.05$). The best regression model is:

ST.RN = 0.766 ST. PRECIP - 4.064

where: ST.RN = storm runoff (mm)

ST.PRECIP = storm precipitation (mm)

This model is significant (R = 0.651, DF = 77) at the 95% confidence level.

TABLE 2. Summarized storm precipitation-runoff characteristics [a, b]

	Hangover	South Bay Dump	Miller	Pallant	Premier	Yakoun
Area (km^2)	20.0	3.9	23.5	76.7	0.8	477.
Discharge						
Instantaneous (m^3/s)						
Mean	1.907	0.223	5.86	5.40	0.034	57.81
Max	5.472	0.366	15.839	12.6	0.202	310.
Min	0.544	0.047	0.407	1.52	0.002	3.87
Timing[a]						
Difference (day)						
Mean	0.47	0.45	0.46	1.3	0.6	2.2
Max	1.68	1.08	1.69	4	3	5
Min	0.20	0.0	0.0	0.0	0.0	0.0
Storm						
Precipitation (mm)						
Mean	19.4	17.38	17.67	36.05	33.38	27.10
Max	35.8	26.75	46.0	121.8	80.2	64.0
Min	4.3	9.5	2.0	6.6	10.6	3.2
Precipitation						
Intensity						
Average (mm/day)						
Mean	9.84	8.95	13.3	11.49	15.49	9.64
Max	17.50	15.25	34.0	17.68	32.2	21.33
Min	4.25	4.75	3.0	4.9	5.3	3.07
Maximum (mm/24 hr)						
Mean	14.19	13.40	13.5	14.30	21.3	13.25
Max	23.00	14.75	34.0	32.0	41.5	37.8
Min	4.25	9.50	3.0	5.3	7.05	3.2
Maximum (mm/hr)						
Mean	2.01	2.04	2.68	—	—	—
Max	5.21	3.85	6.48	—	—	—
Min	0.14	0.52	0.63	—	—	—
Antecedent						
Moisture Index (mm)						
Mean	64.3	5.69	45.3	54.4	57.6	57.5
Max	87.6	75.9	54.4	110.6	96.3	82.0
Min	34.9	41.3	34.9	35.2	35.4	35.6
Storm Runoff (mm)						
Mean	6.4	3.2	13.4	20.5	5.2	21.7
Max	12.8	7.1	39.2	84.0	28.5	118.1
Min	1.3	0.7	1.1	0.2	0.2	0.1
Ratio of						
Precipitation/Runoff						
Mean	4.72	7.35	1.51	11.36	25.3	10.65
Max	12.33	13.57	2.25	68.0	14.6	68.0
Min	1.12	2.11	0.68[b]	1.06	1.7	0.34[b]

[a] Timing differences are based on the lag time between maximum precipitation and peak streamflow.
[b] Values reflect rain-on-snow events.

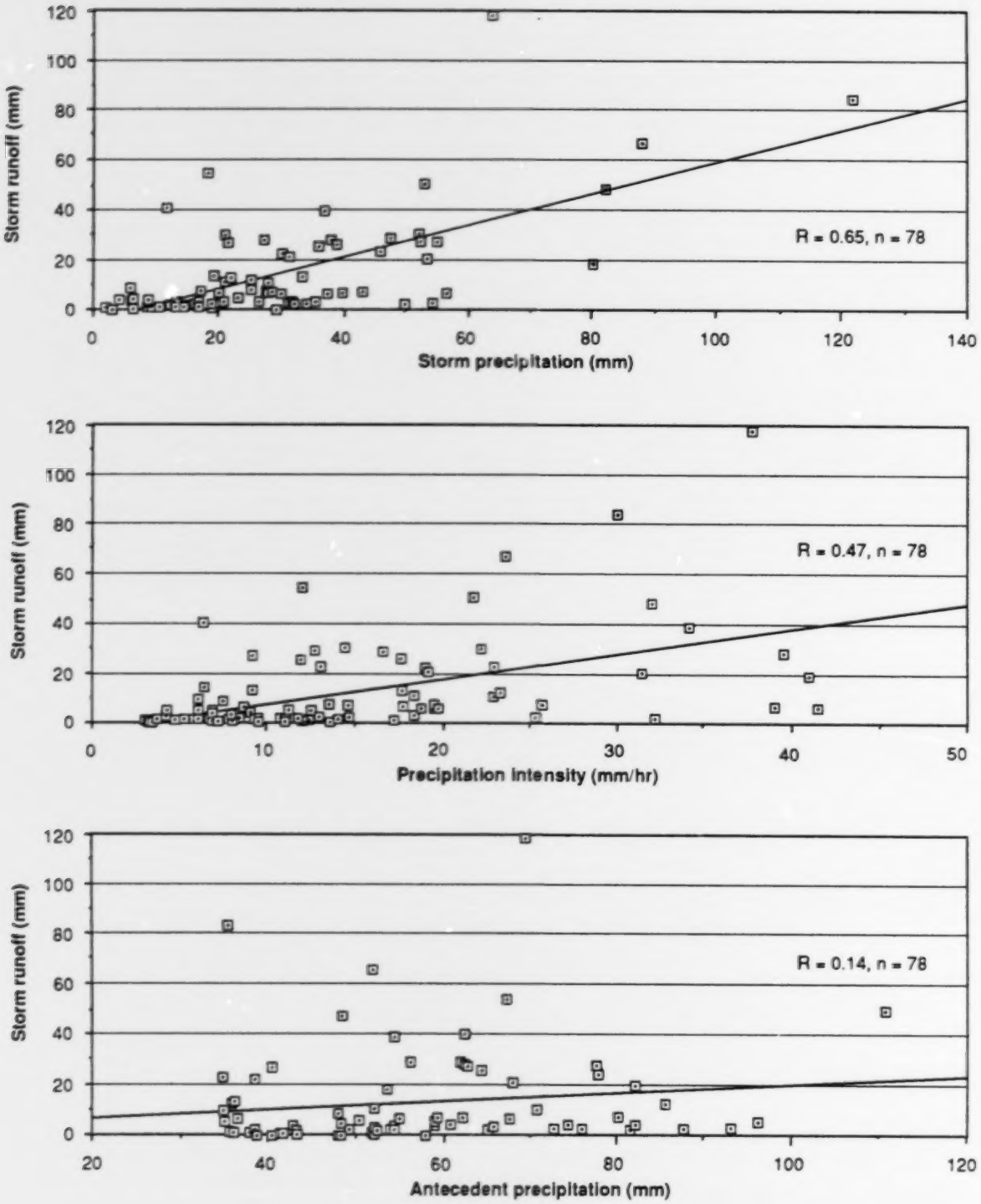

Storm runoff (mm)
Storm precipitation (mm)
R = 0.65, n = 78
Storm runoff (mm)
Precipitation intensity (mm/hr)
R = 0.47, n = 78
Storm runoff (mm)
Antecedent precipitation (mm)
R = 0.14, n = 78

FIGURE 12. Relation between storm runoff and precipitation characteristics (data from Appendix 3).

The multiple regression model hides considerable local variation (see precipitation/runoff ratios in Appendix 4). Precipitation and runoff quantities and relationships for individual watersheds are presented in Figure 13 and Table 3. Relationships are developed for wet, dry, and combined antecedent conditions. In four cases (South Bay Dump Creek, Miller Creek, Premier Creek, and Yakoun River) the January 25-26,1984, event was excluded from regression analyses because the relatively high runoff values corresponding to low precipitation amounts were due to a rain-on-snow occurrence (P. Beaudry, pers. comm. B.C. Min. For., 1986).

Statistically significant relationships, at the 95% confidence level, were established for all stations with the exception of Hangover Creek (Table 3). Although these relationships appear to be fairly good, the points are considerably scattered (Figure 13). The scatter is due to several factors, the most probable being the proximity of the weather station to the watershed and stream gauging station.

TABLE 3. Precipitation-runoff relationship for selected Queen Charlotte Islands watersheds

Precipitation station	Stream flow gauge station	Antecedent moisture condition[a]	No. of storms	Linear regression equation[b]	Correlation coefficient (r)	Critical[c] correlation coefficient	Relationship[d]	Notes
South Bay Dump Creek (Lower)	South Bay Dump Creek	all	6	y = 0.280x - 2.274	0.949	0.878	S	
		wet	3	ID	ID	ID		
		dry	3	ID	ID	ID		
Miller Creek (Upper)	Miller Creek	all	6	y = 0.682x + 1.342	0.927	0.811	S	
		wet	3	ID	ID	ID		
		dry	3	ID	ID	ID		
Hangover Creek	Hangover Creek	all	9	y = 0.137x + 3.711	0.548	0.666	NS	
		wet	6	y = 0.369x + 0.849	0.640	0.811	NS	
		dry	3	ID	ID	ID		
Pallant Creek	Pallant Creek	all	15	y = 0.768x - 7.201	0.985		S	
		wet	9	y = 0.865x - 8.807	0.957	0.666	S	
		dry	6	y = 0.726x + 7.237	0.992	0.811	S	
Sandspit A	Premier Creek	all	19	y = 0.251x - 3.361	0.612	0.433	S	
		all	18	y = 0.197x - 2.596	0.784	0.468	S	omits Jan 25-26, 1984, storm (rain on snow)
		wet	13	y = 0.271x - 3.378	0.537	0.553	S	
		wet	12	y = 0.212x - 2.818	0.795	0.576	S	omits Jan 25-26, 1984, storm (rain on snow)
		dry	7	y = 0.130x -1.310	0.694	0.954	NS	
Sewall Masset	Yakoun River	all	22	y = 0.888x - 2.384	0.728	0.413	S	
		wet	17	y = 1.140x - 6.185	0.632	0.468	S	
		dry	5	y = 0.049x +14.236	-0.063	0.878	NS	

[a] Antecedent moisture conditions:
wet = days before storm received precipitation
dry = 5 days before storm with no precipitation

[b] Linear regression:
y = estimated runoff (mm)
x = total storm precipitation (mm)
V = estimated stormflow volume (m^3)

[c] Critical correlation coefficient (r):
refers to table of r values with df = n - m - 1, where m = no. of independent variables

[d] Relationship:
NS = no significant relationship between precipitation and runoff at 95% confidence level (= 0.05)
S = significant relations exist at = 0.05
ID = insufficient data

The slope of each regression line indicates the proportion of precipitation generating stream runoff. A lower value shows that more precipitation is lost to surface retention (interception, depression storage), infiltration, or evapotranspiration, which contributes less to storm runoff. Without detailed watershed data (soils, vegetation, hydrometeorological), only the general graphical relationships can be considered and not the specific physical factors determining these relationships.

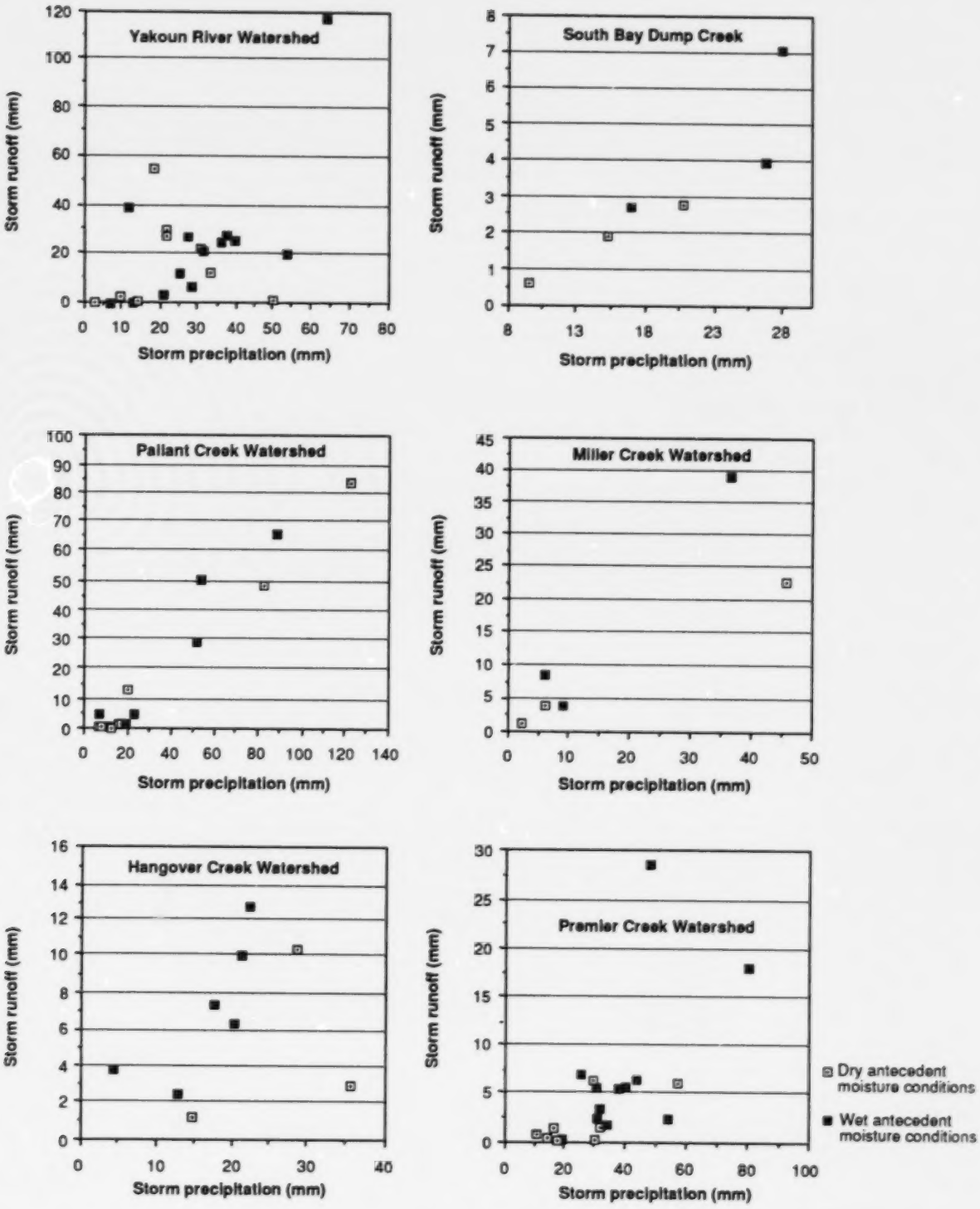


FIGURE 13. Storm precipitation-runoff relationship for selected watersheds. Data from solid symbols represent wet antecedent conditions and empty symbols represent dry conditions (Appendix 3).

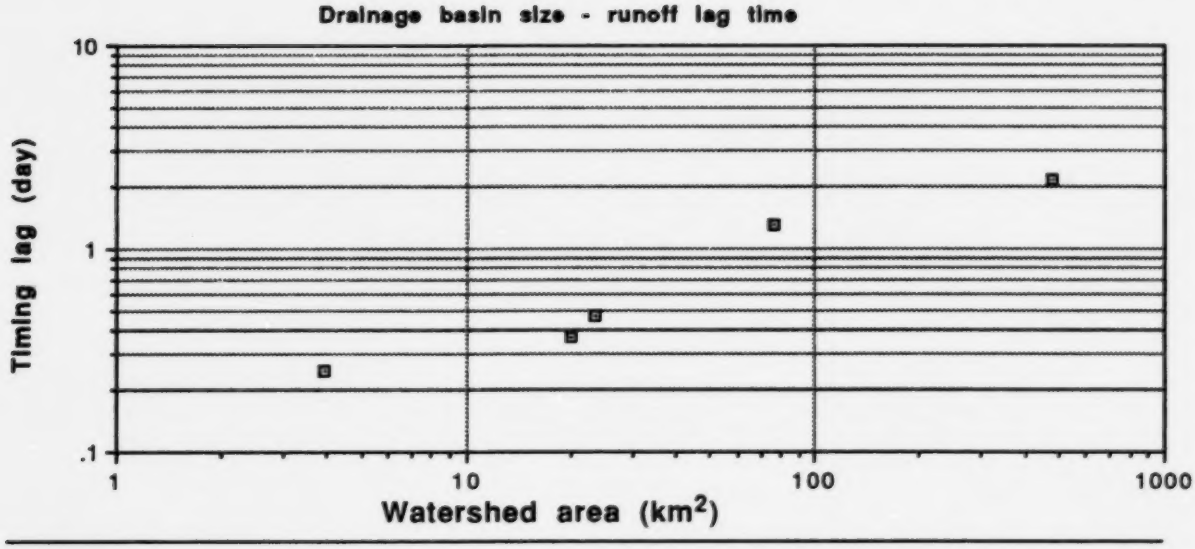
In all cases, more precipitation is contributed directly to storm runoff during periods with wet antecedent conditions. However, the highly variable nature of the slope values suggests that the data used to define precipitation-runoff relationships have limitations.

The relationship between precipitation and storm runoff is presented as a set of statistically significant regression models which enables very little interpretation in physically meaningful terms. In addition, several problems seriously limit the usefulness of the documented relationships. The more important of these are:

1. equipment malfunctions: many larger magnitude storms could not be considered because either the rain gauge or stream stage gauge (or both) malfunctioned during the event. Often the rating curve required to calculate discharge was not established after the storms.
2. questionable representativeness of hydrometeorological stations: in many cases the only weather data available were from surrounding areas, which may not have been typical of the stream gauged basin. Also, the spatial deficiencies of the precipitation network severely limits the reliability of derived relationships.
3. incompatibility of data types: this includes a mix of daily and hourly data. In many cases, hourly streamflow data could only be paired with daily precipitation data.
4. inconsistent data collection: this includes different practices regarding day lengths (e.g., AES days begin at 0400 hours local time) and alternating data retrieval (e.g., daily on weekdays and cumulated totals for the weekends).
5. poor data quality: this is particularly serious for the FFIP data. Problems include poor field booking practices, illegible charts, record gaps, and the general lack of recorder calibration.
6. potential undercatch by RAB and AES rain gauges in exposed locations.

5.2 Timing

The lag period between the time of maximum precipitation and the time of runoff for all stations considered is included in Table A3.1 and summarized in Figure 14(b) and Table 2. Lag times increase with increased drainage basin size. The longest lag period, averaging between 1.7 and 2.2 days, occurs in the Yakoun watershed. The shortest lag times, averaging less than 12 hours, occur in South Bay Dump, Hangover, and Miller creek watersheds.



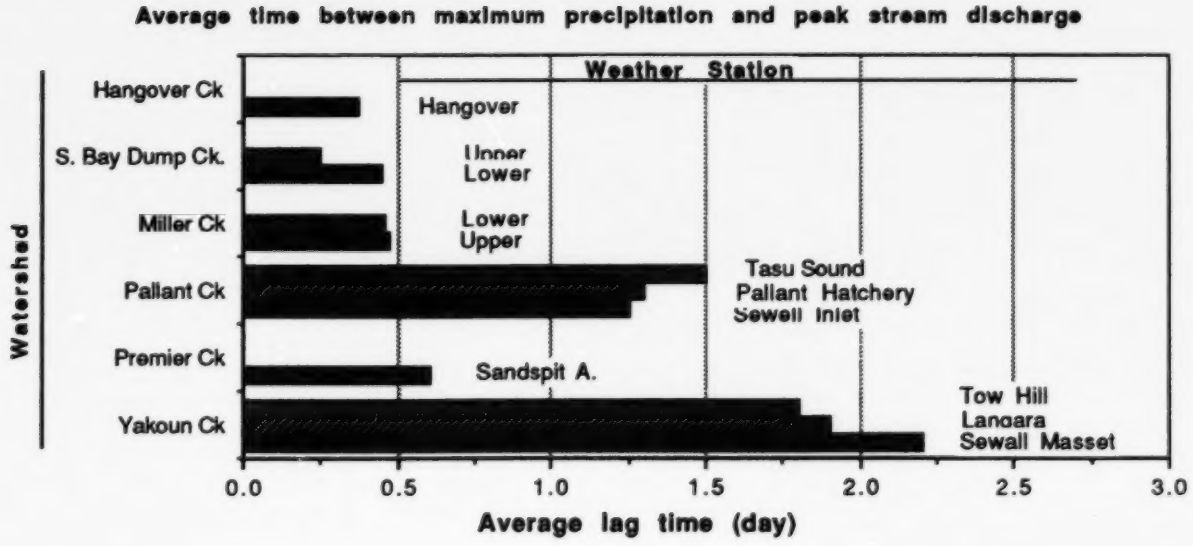


FIGURE 14. Relationship between time of maximum precipitation and peak stream discharge.

6 ESTIMATING FLOWS FOR UNGAUGED WATERSHEDS

The relationship between drainage basin area and stormflow is shown in Figure 15. The mean annual maximum instantaneous discharge (recurrence interval equal to 2.33 years) indicates that the largest basin (Yakoun) is relatively drier than the other watersheds. This can be shown by fitting a straight line through the smaller four basin values of mean annual maximum instantaneous discharge. This line intersects the Yakoun River data point corresponding to the 25-year recurrence interval discharge. In other words, the larger watershed (Yakoun) receives relatively small runoff amounts compared to the other basins. This limits the usefulness of the area-discharge relationship because including watersheds with different precipitation regimes is inappropriate. For this reason, and because no return period data are available for the FFIP study watershed (Hangover and Bonanza), it is not possible to use higher frequency values to relate basin area to discharge.

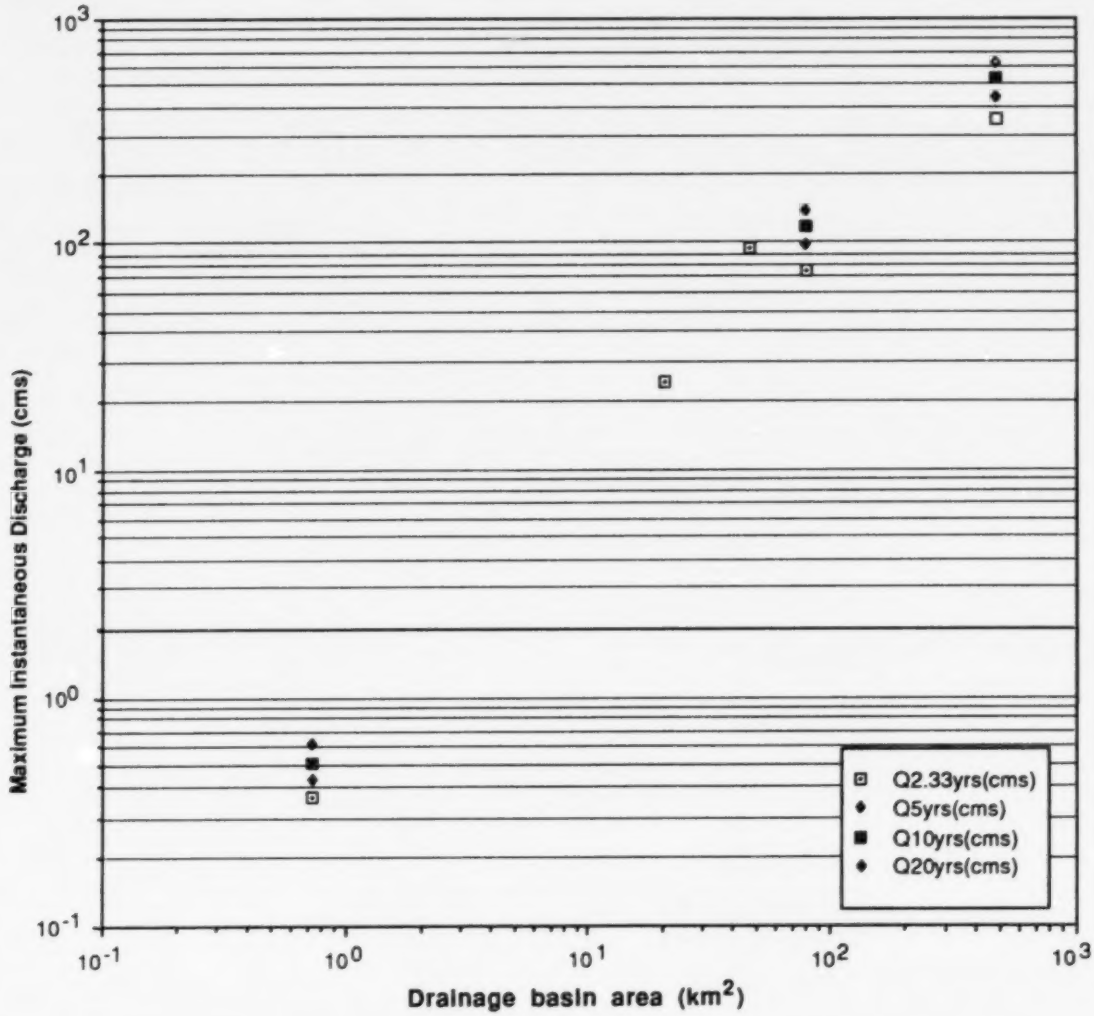


FIGURE 15. Relationship between drainage basin area and instantaneous flood flows of various frequencies (data from Table 1 and Appendix 2).

Figure 15 shows that the drainage basin-stormflow graphs are valid only in areas with similar biophysical conditions (e.g., climate, vegetation, and geology). Campbell and Sidle (1984) and Adams *et al.* (1986) show that statistically significant relationships can be developed between basin area and stormflow in homogeneous areas. Because there are insufficient data on the Queen Charlotte Islands to develop these for each precipitation zone, a multiple regression model has been set up that incorporates several biophysical variables. However, only two independent variables (m=2) are possible with a sample size of five (n=5) because the degrees of freedom are reduced to two (n-m=2). The most appropriate model is:

$$\log Q_{2.33} = 1.071 \log AREA + 1.522 \log PRECIP - 5.4$$

where: $Q_{2.33}$ = mean annual maximum instantaneous discharge (m^3/sec);

AREA = drainage basin area (km^2)

PRECIP = mean annual precipitation (mm, from Figure 9);

log = base 10.

This relationship is significant at the 95% confidence level (R^2 = 0.989; n=5) but caution must be exercised because of the very small sample size. It is not possible to estimate the discharge for any other recurrence interval based on the present data base. To estimate the flood flows associated with other return periods, long-term records are required from several more drainage basins with different geographic settings and watershed sizes.

7 CONCLUSION

This report documents and assesses the basic precipitation and runoff data currently available for the Queen Charlotte Islands. It also provides an initial evaluation of these data to satisfy frequently received requests for data and their interpretations, and offers supplemental information for other resource planning reports.

Data from all long-term provincial and federal agencies were used, in addition to short-term data collected as part of ongoing resource planning projects. Unfortunately, the combination of poor data, insufficient number of stations, and limited station record length make the validity of many derived hydrometeorological relationships questionable. Additional climate and stream gauging stations, rigorously monitored, are required if more confidence is to be placed on the analyses.

The Queen Charlotte Islands have been stratified into regions with homogeneous precipitation regimes. This enables "first estimate" calculations of precipitation levels for many areas with no precipitation records. Based on this regionalization, a model has been developed which relates annual precipitation (ANN PRECIP, in mm) to longitude (LONG, in degrees) and latitude (LAT, in degrees). Elevation is implicit in the geographic coordinates. The statisically significant relationship is:

$$\text{ANN PRECIP} = 1342.341\ \text{LONG} - 1372.320\ \text{LAT} - 104449.480$$

Precipitation variability with elevation was considered. However, short and inconsistent records give graphical relationships limited value. The data indicate that precipitation increases by 30-40 mm for each 100 m increase in elevation. This estimate gives annual precipitation in excess of 5000 mm in mountainous zones. Although precipitation probably does not increase linearly, the estimate is similar to that provided by Williams (1968).

The frequency of large magnitude rainstorms and runoff events was also presented. Regionalized precipitation data have been used to relate monthly runoff to monthly precipitation. Statistically significant relationships are presented for two wetter regions of the islands.

Precipitation characteristics, such as storm precipitation amounts and intensities, antecedent moisture conditions, and time of year, were obtained from short-term hydrometeorological records and used to develop

a regression model relating storm runoff (ST.RN, in mm) to storm precipitation (ST PRECIP, in mm). A statistically significant relationship was found:

$$ST.RN = 0.766\ ST\ PRECIP - 4.064$$

Where no data exists for storm precipitation characteristics, a relationship for estimating mean annual peak flows, based upon watershed properties and mean annual precipitation, is best expressed as:

$$LOGQ_{2.33} = 1.071\ LOG\ AREA + 1.522\ LOG\ PRECIP - 5.4$$

where: $Q_{2.33}$ = mean annual maximum instantaneous discharge (m^3/s)

AREA = drainage basin area (km^2)

PRECIP = mean annual precipitation (mm)

LOG = base 10

Although the relationship is significant at the 95% confidence level, it should be used with caution because of the very small sample size. There are insufficient data to estimate stream discharges with larger recurrence intervals.

The limitations noted within this report indicate that long-term hydrometeorological data must be collected for the Queen Charlotte Islands so that more reliable precipitation-runoff relationships and more confident return period estimates can be developed. Clearly, more streamflow information is required if progress is to be made. More stream gauging stations that are representative of the different geographic locations (three main physiographic regions) and a variety of watershed sizes are necessary. Also, more precipitation stations in each region — particularly along the west coast, within the South Moresby Island area, and at higher elevations — are required.

The acquisition of hydrometeorological information represents a huge and long-term economic investment. The improbability of hydrometeorological stations being installed and maintained in the near future leaves only a limited data base on which to develop important resource management plans. The work presented here is just a beginning, and it is hoped that as more "project-specific" data are collected, analyzed, and submitted to government agencies for review, these will be used to refine the precipitation-runoff relationships described in this report.

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APPENDIX 1. Assessment of precipitation variability on the Queen Charlotte Islands

PRECIPITATION

Introduction

Precipitation is a difficult factor to assess because it is highly variable over short distances, particularly in areas of diverse topography such as the Queen Charlotte Islands. If an adequate network of precipitation sampling stations is available, it would be possible to regionalize precipitation on the basis of spatial variability. The short-term precipitation measuring network on the Queen Charlotte Islands is dense in comparison with networks in other areas of British Columbia.

The objectives of this appendix are:

1. to describe homogeneous regions of annual precipitation in the Queen Charlotte Islands; and
2. to describe the factors contributing to precipitation variability, and to determine if a significant regression model can be developed for each region.

Methods

Data requirements

Data required for this regionalization include records of monthly total precipitation for each year of record and sampling site elevation, longitude, latitude, and aspect. Since site characteristics influence precipitation amounts recorded at the site, they also influence the regional variability of precipitation.

Data sources

Data are available from two sources. First, the Atmospheric Environment Service (AES) operates eight weather stations on the islands. The AES data are carefully controlled and are of high quality; no problems were encountered with these data.

Second, the B.C. Ministry of Environment's Air Studies Branch (ASB) operated 55 short-term (5 year record) stations on the islands (B.C. Ministry of Environment 1980). Data quality problems were encountered with records, and several of the stations had only statistically estimated averages and no actual monthly values. Only 41 station records could be obtained of the original 55 stations. These were subjected to the following selection criteria:

1. no more than 2 days could be missing from any 1 month (important in high intensity rainfall areas); and
2. records had to be 4 years (between 1970 and 1980) in length.

After reviewing the 41 station records, a further 6 stations were excluded. As a result, the final data set consisted of monthly values of total precipitation for 35 stations covering 4 years of record. The station locations and data records are given in Figure 1 and Table A1.1, respectively. That the stations are concentrated on the eastern side of Graham Island makes the precipitation data less appropriate for regionalization. Consequently, these data must be considered in conjunction with study results.

Data groupings

The grouping procedure followed is: a) monthly precipitation; b) hierarchical grouping; c) F-test of within group variance; d) Duncan's new multiple range test to check hierarchical groups; e) multiple regression of expected controlling factors within each group (e.g. elevation, latitude, longitude and aspect).

TABLE A1.1. Location of selected climate stations on the Queen Charlotte Islands

Station name	No.	Latitude (deg.	min.	sec)	Longitude (deg.	min.	sec)	Elevation (m)	Aspect (deg)	Record length[a]	1976-80 Mean annual precipitation (mm)
RAB:											
Black Bear	1	53	30	55	132	08	30	21	20	1976-80	1565
Dawson Inlet	2	53	12	55	132	29	10	9	140	1976-80	3544
Deena Creek	3	53	07	30	132	14	29	75	190	1976-80	3254
Eden Lk. ASB	4	53	54	28	132	40	00	41	170	1976-82	2091
Ferguson Pt.	5	53	39	22	132	18	31	64	220	1976-80	1382
Gospel Pt.	6	53	24	00	132	30	50	34	220	1976-83	2276
Gray Bay	7	53	07	05	131	42	38	20	340	1976-80	1911
Juskatla El	8	53	34	27	132	22	43	128	140	1976-83	2193
Kagen Bay	9	53	14	56	132	10	19	91	150	1976-80	1977
Kliki	10	54	02	51	131	52	50	11	160	1976-80	1545
Mamin River	11	53	34	35	132	20	00	61	150	1976-80	1808
Marie Lk. N	12	53	33	10	132	17	15	226	0	1976-84	2130
Marie Lk. Rid.	13	53	32	00	132	17	43	398	270	1976-83	1936
Marie Lk. Low	14	53	32	02	132	19	27	64	0	1976-80	2035
Marie Lk. S	15	53	32	15	132	18	25	207	240	1976-80	2051
Mayer Lk.	16	53	38	18	132	03	30	35	100	1976-80	1344
Naden Pt.	17	53	58	14	132	37	08	20	350	1976-80	1476
Survey Ck.	18	53	19	48	132	10	33	133	240	1976-84	2247
Tatzun Lk.	19	53	42	13	132	36	15	101	90	1976-83	2091
Tlell R.	20	53	34	37	131	56	16	9	120	1976-80	1096
Twin	21	53	48	52	131	49	55	210	200	1976-80	1431
Watun Ck.	22	53	54	50	132	05	10	66	270	1976-80	1466
Yakoun R.	23	53	31	05	132	12	40	35	350	1976-83	1710
Marie Lk. Hl.	24	53	32	15	132	17	46	468	90	1976-80	1728
Penthouse	25	53	21	48	132	26	15	378	160	1976-83	2487
Camilla	26	53	21	00	132	19	30	251	220	1976-83	3927
Rennell Sound	27	53	20	33	132	25	30	12	220	1976-80	3098
AES:											
Cape St. James	28	51	56	00	131	01	00	89	---	1967-Present	1746
Langara	29	54	15	00	133	03	00	41	---	1973-Present	1978
Masset CPS	30	54	02	00	132	04	00	12	---	1971-Present	1384
Sandspit A	31	53	15	00	131	49	00	5	---	1971-Present	1542
Sewell Inlet	32	52	53	00	132	00	00	12	---	1973-Present	4302
Sewall Masset Inlet	33	53	46	00	132	18	00	3	---	1974-Present	1383
Tasu Sound	34	52	46	00	132	03	00	15	---	1966-1984	4205
Tlell	35	53	29	00	131	56	00	5	---	1971-Present	1030

[a] Record length included for completeness. Only the 4 years of 1976-80 were considered in the analyses presented here.

All procedures are standard with the possible exception of step b above. The UBC Computer Library Program "C GROUP" (Lai 1982) was used for initially grouping the data. In this procedure a set of attributes (monthly precipitation — 48 values per station) is ascribed to each station. Stations are then sequentially grouped. Each new group is formed from the two stations (groups) whose total set of attributes are most similar. Therefore, at any point in the grouping procedure there will be minimum variance amongst the attributes within the groups. The within group variance acquired on joining two stations is indicated by the error index (I):

$$I = \frac{\sum_{i=1}^{m} (X_{ij} - X_{ik})^2}{nj + nk}$$

where: X = attribute from 1 to m

j, k = individual stations to be grouped

n = number of attributes per record

By repetition of the process, grouping proceeds from N groups (stations) to 1 group (all stations together). Multiple regression fitting was conducted by the UBC Computer Library Package UBC TRP (Le and Tenisci 1978).

Results and Discussion

Hierarchical grouping was conducted using the 35 stations. The error index terms are plotted as cumulative totals and major breaks in the slope of the line are used to indicate the number of resultant groups. Four groups were selected and within group variance was tested. F-tests indicate that there is no significant difference ($\alpha = 0.05$) amongst stations within each of the four groups. There is a significant difference (at $\alpha = 0.05$) between groups, and Duncan's multiple range test shows that all groups are significantly different. This procedure results in four major groups, or zones, of similar precipitation on the Queen Charlotte Islands. The geographical pattern is shown in Figure 8. The annual precipitation range for each refers to the 95% confidence limits.

The four zones presented indicate that physiography is a major influence controlling the spatial distribution of precipitation over the Queen Charlotte Islands. The areas of low precipitation are associated with the low plateau in northeastern Graham Island. Precipitation gradually increases towards the west where the Queen Charlotte Range extends along the entire length of Moresby Island. The results suggest that it should be possible to develop a regression model to relate precipitation with elevation and location.

Before doing so, however, the usefulness of the groups shown in Figure 8 must be questioned. This grouping approach is unsatisfactory because of the relatively small sample size (N = 35 stations) and the uneven and non-random distribution of sampling stations. In fact, sampling is sufficiently sparse that delineation between groups over large areas is little better than standard extrapolation techniques. This is discouraging because the sampling network is superior to most. The problem would not have been as serious if records for the other 20 stations on the islands had been more reliable.

The sample size problem undermines attempts to determine relations between precipitation and controlling factors. When all stations were combined (N = 35, Table A1.1) the best relationship is:

$$Y = 104449.480 + 1342.341\ X_1 - 1327.320\ X_2$$

where: X_1 = longitude (degrees)

X_2 = latitude (degrees)

Y = mean annual precipitation (mm)

This relationship accounts for 44% of the variation in precipitation (significant at $\alpha = 0.05$, df = 32). Elevation is implicit in geographic location. Aspect was not included as a variable because it was not available for all stations.

APPENDIX 2. Frequency analysis results

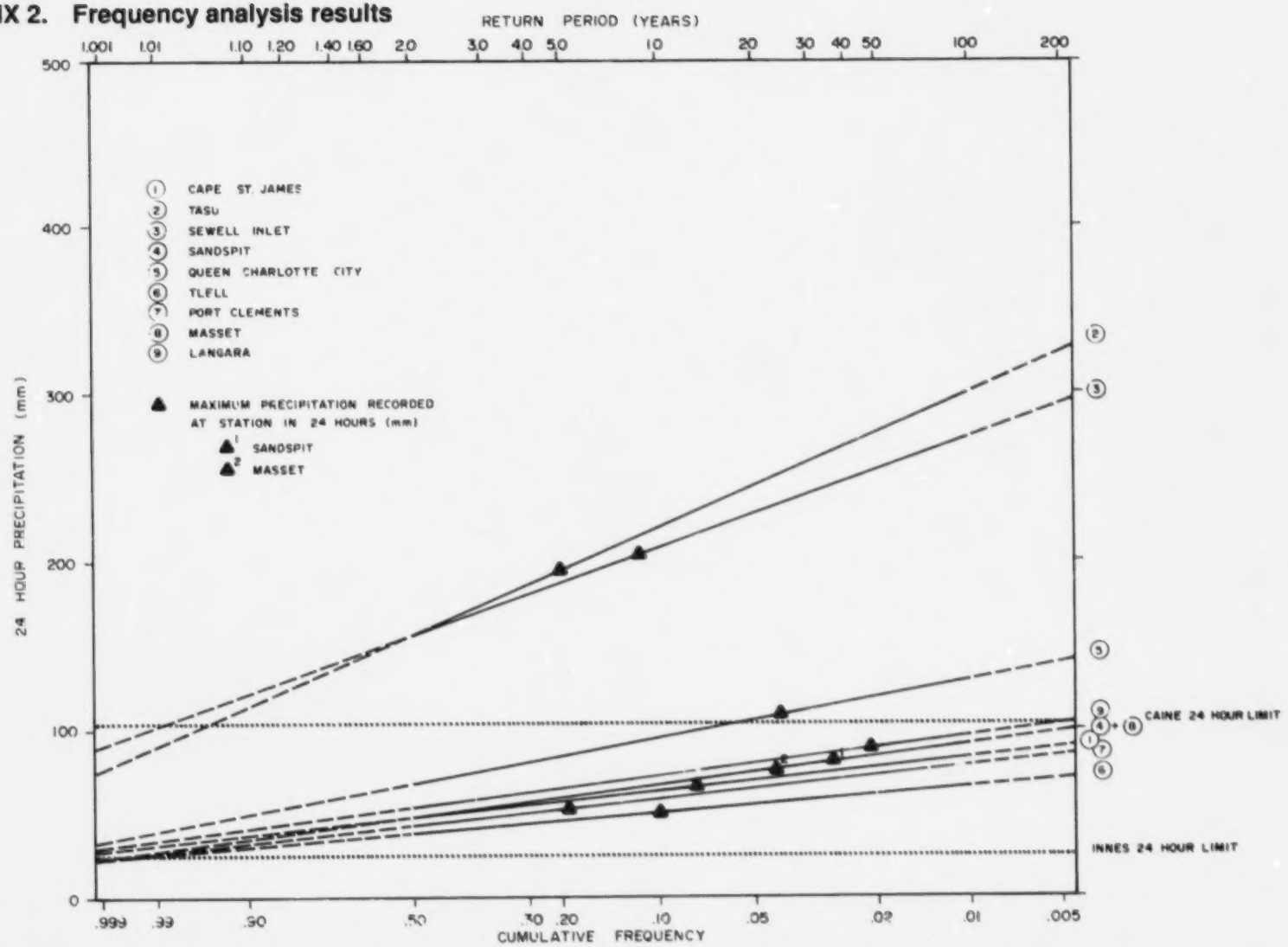

FIGURE A2.1. Frequency-magnitude estimates of 24, 48 and 72 hour precipitation at nine Queen Charlotte Islands weather stations.

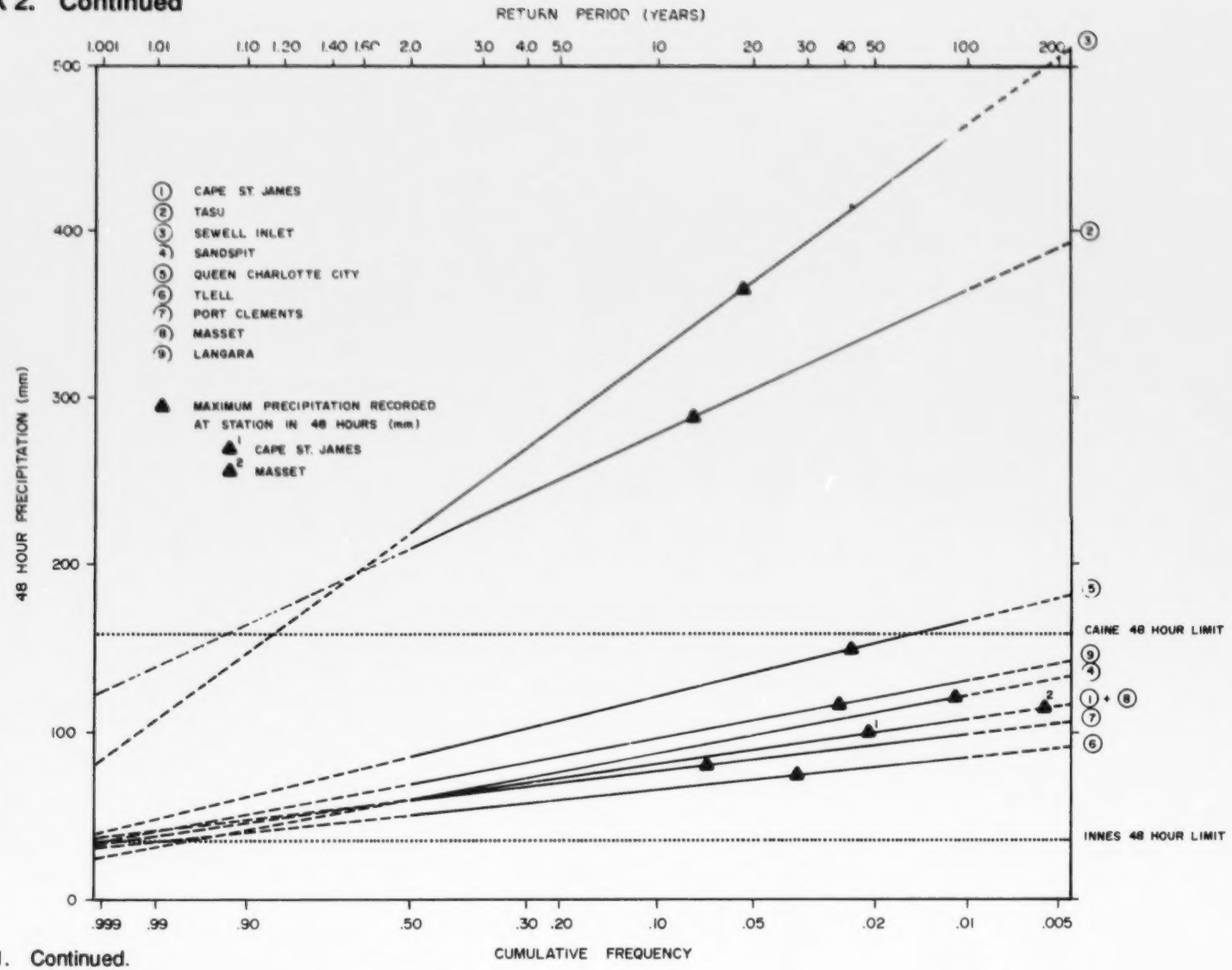

FIGURE A2.1. Continued.

APPENDIX 2. Continued

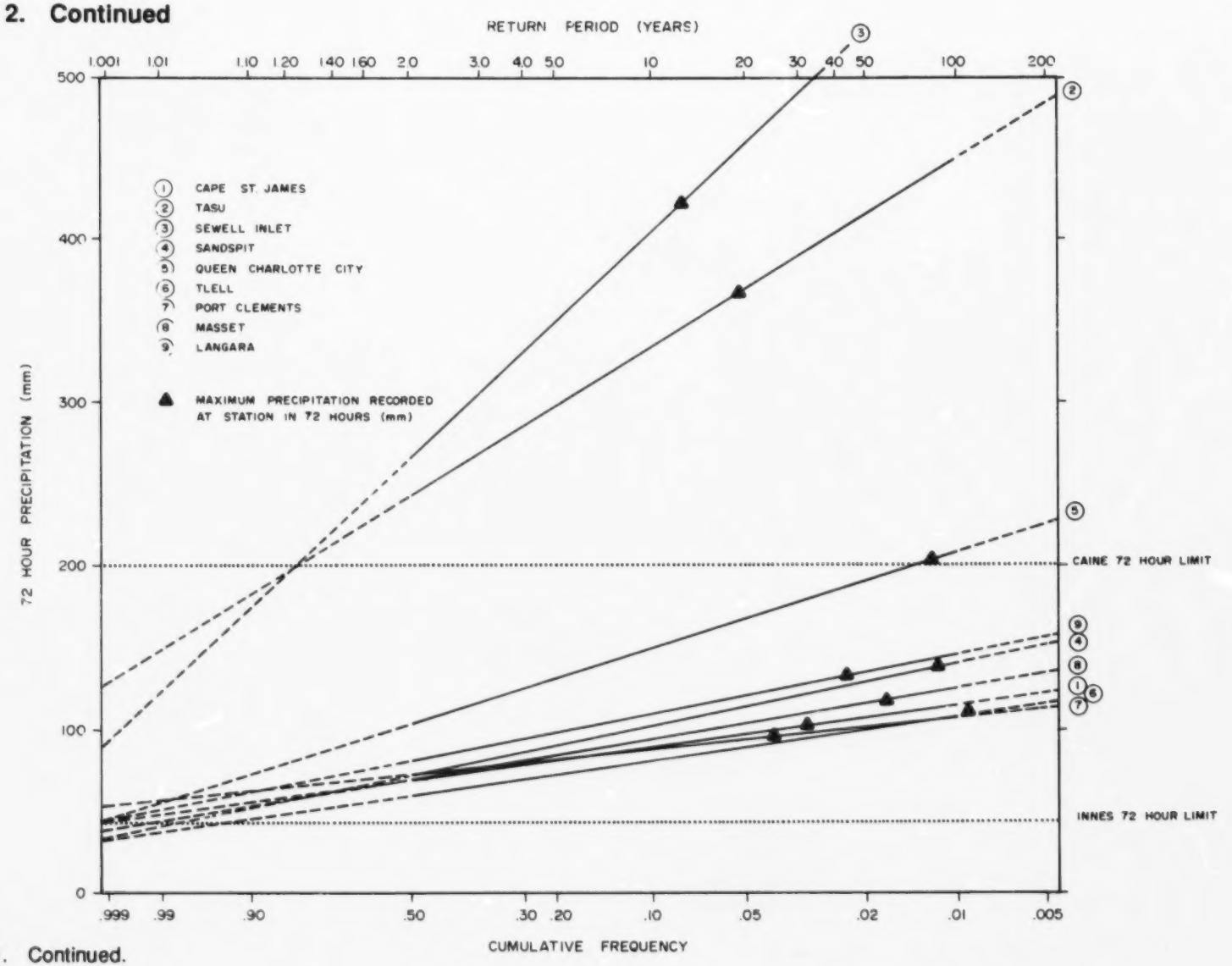

FIGURE A2.1. Continued.

APPENDIX 2. Continued

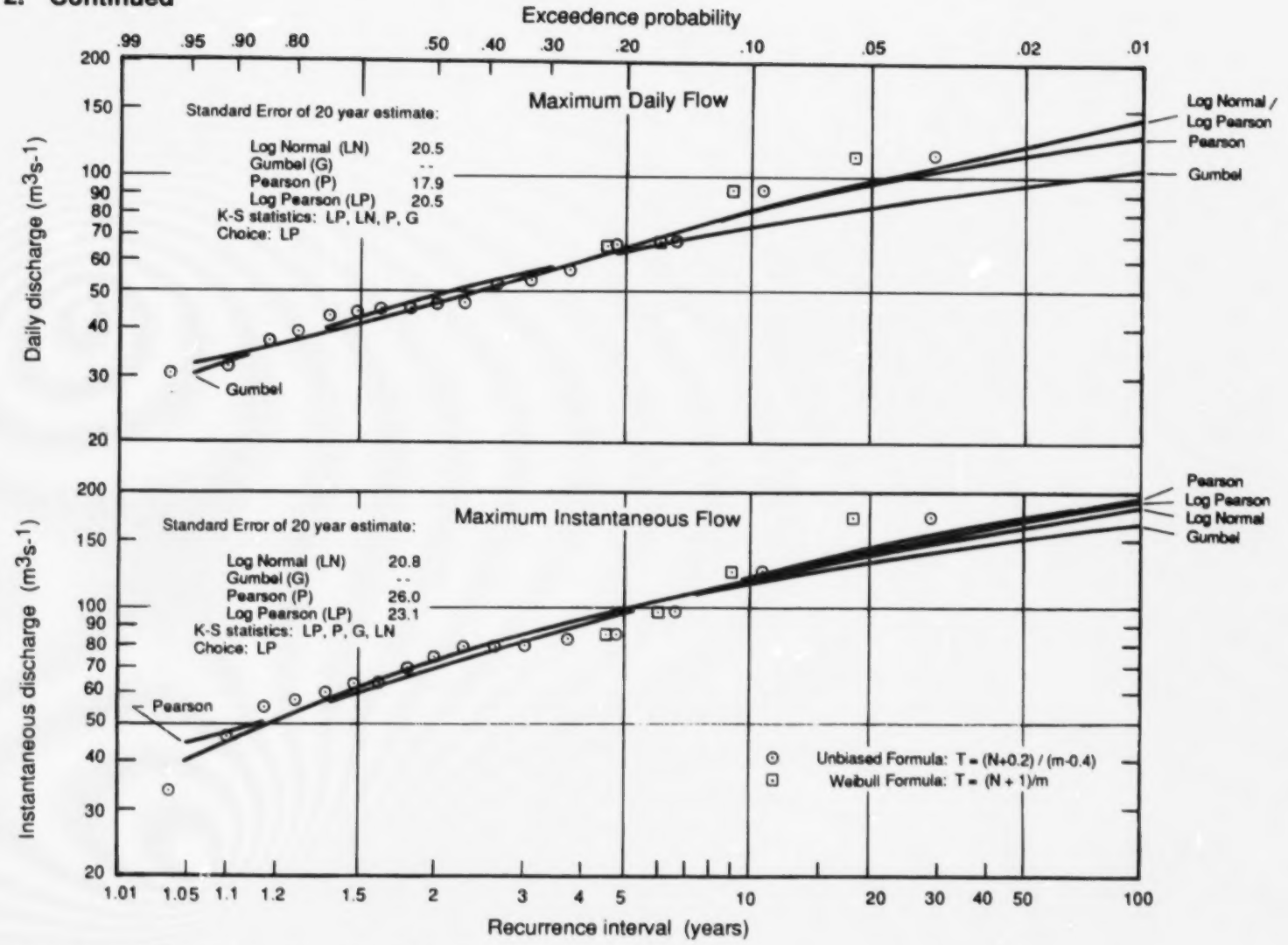

FIGURE A2.2. Streamflow recurrence interval graphs - Pallant Creek.

APPENDIX 2. Continued

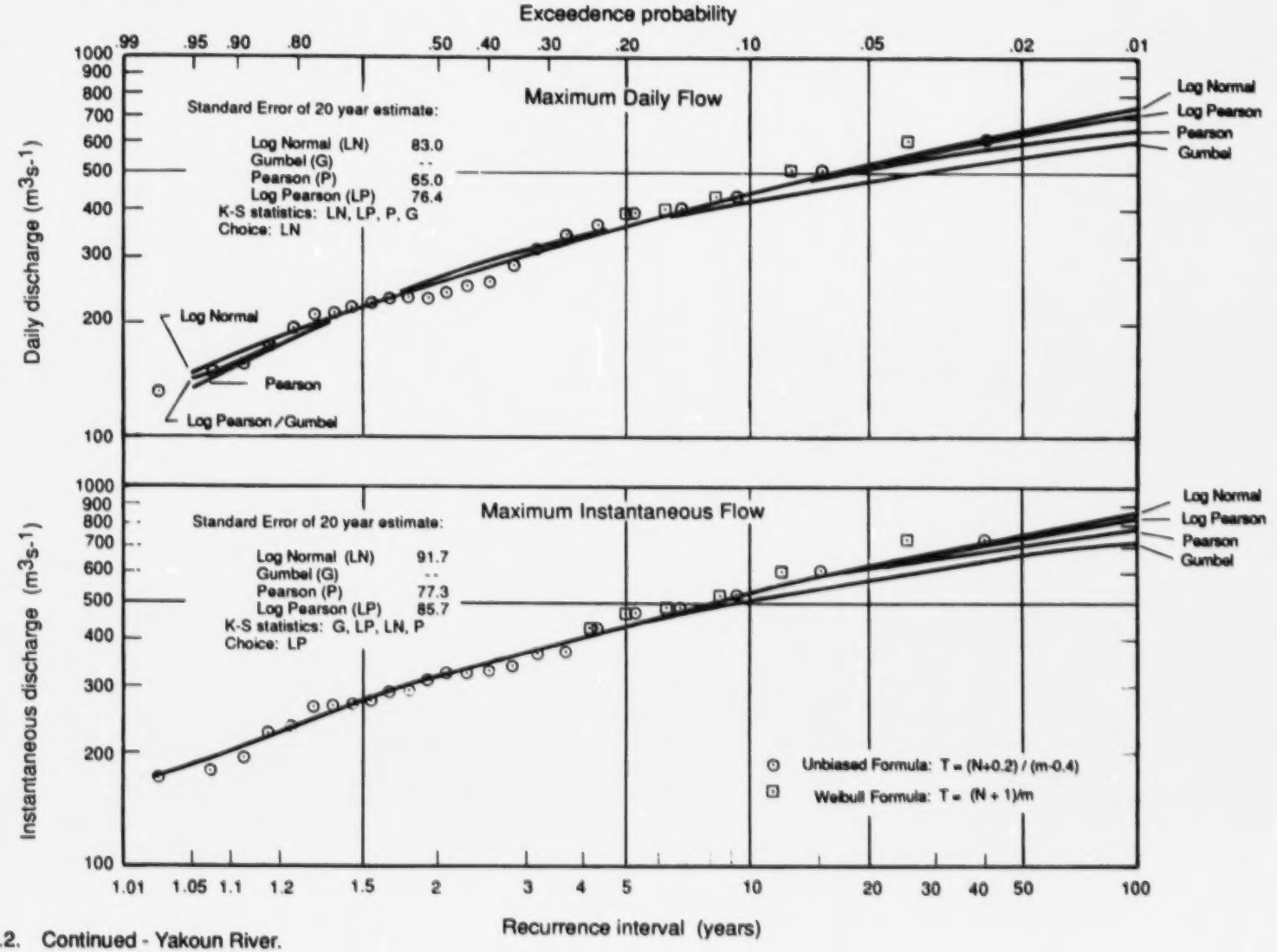
Exceedence probability
.99 .95 .90 .80 .50 .40 .30 .20 .10 .05 .02 .01
Maximum Daily Flow
Standard Error of 20 year estimate:
Log Normal (LN) 83.0
Gumbel (G) --
Pearson (P) 65.0
Log Pearson (LP) 76.4
K-S statistics: LN, LP, P, G
Choice: LN
Log Normal
Pearson
Log Pearson /Gumbel
Log Normal
Log Pearson
Pearson
Gumbel
Daily discharge (m3s-1)
Maximum Instantaneous Flow
Standard Error of 20 year estimate:
Log Normal (LN) 91.7
Gumbel (G) --
Pearson (P) 77.3
Log Pearson (LP) 85.7
K-S statistics: G, LP, LN, P
Choice: LP
Unbiased Formula: T = (N+0.2) / (m-0.4)
Weibull Formula: T = (N + 1)/m
Instantaneous discharge (m3s-1)
1000 900 800 700 600 500 400 300 200 100
1.01 1.05 1.1 1.2 1.5 2 3 4 5 10 20 30 40 50 100
Recurrence interval (years)

FIGURE A2.2. Continued - Yakoun River.

APPENDIX 2. Continued

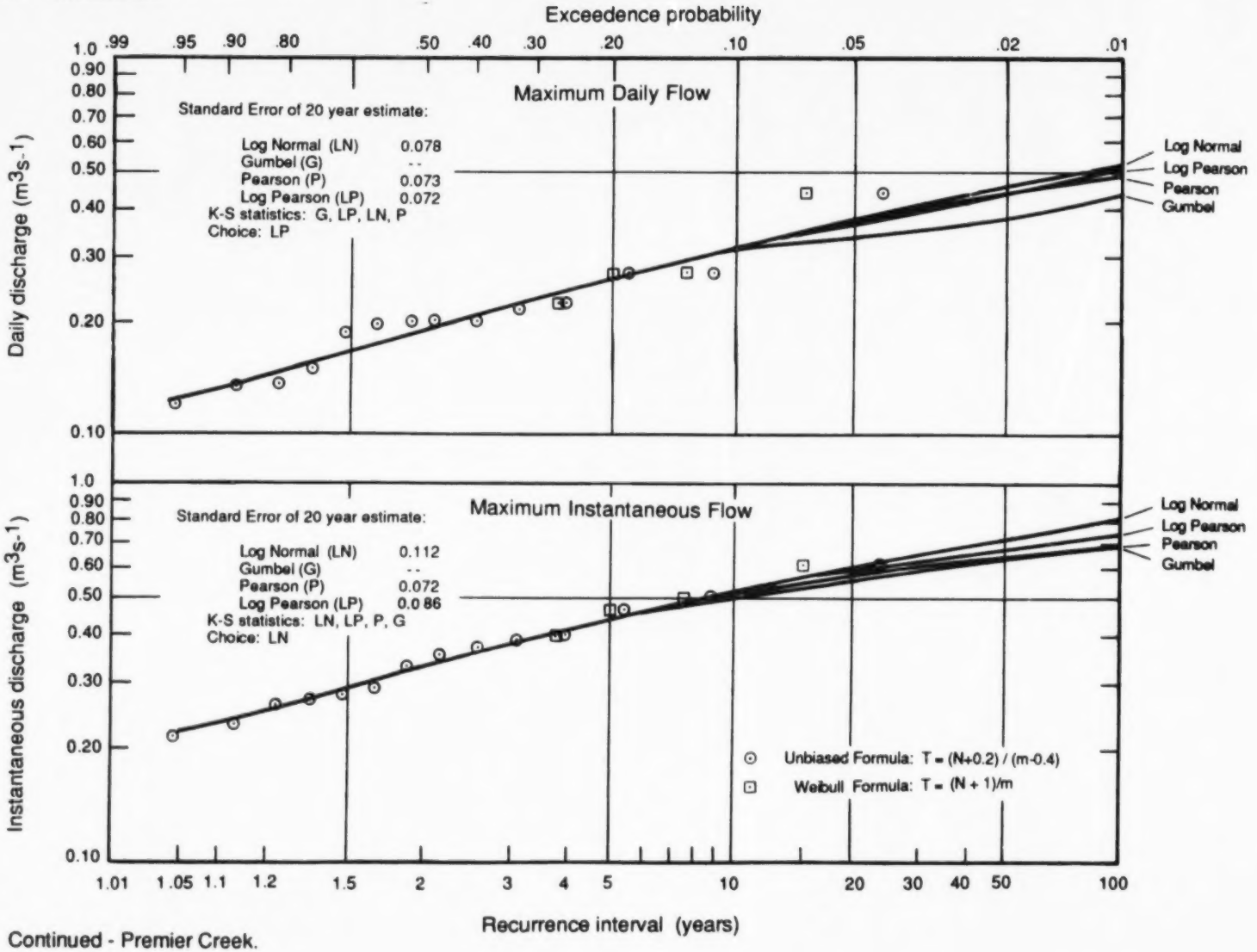

FIGURE A2.2. Continued - Premier Creek.

TABLE A2.1. Probable precipitation magnitudes and return periods for selected Queen Charlotte Islands AES stations. (All data analysis performed by Environment Canada, Atmospheric Environment Service, Canadian Climate Centre, Downsview, Ontario.)

Station name, number, and elevation	Years of record analyzed	Confidence limits	Return period (Yr)	Return period rainfall amounts (mm) 1 Day	2 Day	3 Day	4 Day	5 Day
Cape St. James	53	50%	2	48 ± 1	60 ± 1	70 ± 1	80 ± 1	88 ± 1
1051350			5	57 ± 2	73 ± 2	82 ± 2	94 ± 2	103 ± 2
89 m			10	63 ± 2	81 ± 3	90 ± 3	103 ± 3	113 ± 3
			25	71 ± 3	92 ± 4	100 ± 4	114 ± 4	125 ± 4
			50	77 ± 3	99 ± 4	107 ± 4	122 ± 5	134 ± 5
			100	82 ± 4	107 ± 5	114 ± 5	130 ± 6	144 ± 6
Max. Ppt. Recorded (mm) (yr of occur.)				64 [30]	99 [79]	102 [79]	111 [79]	135 [75]
Probable Max. Ppt. possible				226	308	308	350	384
Tasu Sound	17	50%	2	156 ± 6	208 ± 7	242 ± 9	278 ± 10	303 ± 10
1058003			5	194 ± 11	249 ± 12	297 ± 16	338 ± 17	362 ± 17
15 m			10	219 ± 15	277 ± 16	334 ± 21	378 ± 23	402 ± 23
			25	251 ± 20	311 ± 22	381 ± 29	427 ± 31	451 ± 31
			50	275 ± 24	337 ± 26	415 ± 35	464 ± 37	488 ± 37
			100	298 ± 28	362 ± 30	449 ± 40	501 ± 43	524 ± 43
Max. Ppt. Recorded (mm) (yr of occur.)				194 [80]	287 [74]	367 [69]	427 [69]	471 [69]
Probable Max. Ppt. possible				750	866	1140	1255	1273
Sewell Inlet	9	50%	2	155 ± 7	218 ± 15	266 ± 20	295 ± 19	324 ± 18
1057192			5	186 ± 12	284 ± 26	350 ± 33	375 ± 32	400 ± 30
12 m			10	207 ± 17	327 ± 35	405 ± 45	429 ± 43	450 ± 40
			25	233 ± 22	382 ± 47	476 ± 60	497 ± 58	513 ± 54
			50	253 ± 27	423 ± 56	528 ± 72	547 ± 69	559 ± 65
			100	272 ± 31	463 ± 65	579 ± 84	596 ± 81	606 ± 75
Max. Ppt. Recorded (mm) (yr of occur.)				203 [78]	364 [78]	422 [78]	445 [78]	467 [78]
Probable Max. Ppt. possible				662	1269	1614	1625	1565
Sandspit	35	50%	2	48 ± 1	60 ± 2	72 ± 2	82 ± 2	93 ± 2
1057050			5	59 ± 2	76 ± 3	90 ± 4	100 ± 4	112 ± 4
5 m			10	67 ± 3	87 ± 4	103 ± 5	112 ± 5	125 ± 5
			25	76 ± 4	101 ± 6	118 ± 7	127 ± 7	141 ± 7
			50	83 ± 5	111 ± 7	129 ± 8	138 ± 8	153 ± 8
			100	90 ± 6	121 ± 8	141 ± 9	150 ± 9	165 ± 10
Max. Ppt. Recorded (mm) (yr of occur.)				80 [52]	120 [78]	139 [78]	145 [78]	158 [78]
Probable Max. Ppt. possible				269	385	440	444	475
Queen	30	50%	2	67 ± 3	85 ± 3	103 ± 4	119 ± 4	132 ± 4
Charlotte			5	84 ± 3	106 ± 5	131 ± 6	150 ± 7	163 ± 7
City			10	94 ± 5	121 ± 6	150 ± 8	171 ± 9	183 ± 9
1056590			25	108 ± 6	138 ± 8	173 ± 11	197 ± 12	209 ± 12
15 m			50	118 ± 8	152 ± 10	191 ± 13	216 ± 15	228 ± 14
			100	128 ± 9	165 ± 12	208 ± 15	236 ± 17	247 ± 17
Max. Ppt. Recorded (mm) (yr of occur.)				107 [35]	148 [35]	202 [35]	228 [35]	239 [35]
Probable Max. Ppt. possible				373	493	647	723	726
Tlell	33	50%	2	39 ± 1	50 ± 1	60 ± 2	67 ± 2	75 ± 2
1058190			5	46 ± 1	59 ± 2	73 ± 3	80 ± 3	88 ± 3
5 m			10	50 ± 2	65 ± 3	81 ± 4	89 ± 4	97 ± 4
			25	56 ± 3	73 ± 3	92 ± 5	100 ± 5	108 ± 5
			50	60 ± 3	79 ± 4	100 ± 6	108 ± 6	116 ± 6
			100	65 ± 4	84 ± 5	108 ± 7	116 ± 7	124 ± 7
Max. Ppt. Recorded (mm) (yr of occur.)				50 [51]	73 [78]	109 [78]	113 [78]	118 [78]
Probable Max. Ppt. possible				178	234	322	336	340

TABLE A2.1. Continued

Station name, number, and elevation	Years of record analyzed	Confidence limits	Return period (Yr)	Return period rainfall amounts (mm) 1 Day	2 Day	3 Day	4 Day	5 Day
Port Clements	9	50%	2	44 ± 2	60 ± 2	72 ± 2	83 ± 3	95 ± 4
1056250			5	53 ± 4	70 ± 4	82 ± 4	97 ± 6	111 ± 6
8 m			10	59 ± 5	77 ± 5	88 ± 5	107 ± 8	121 ± 8
			25	67 ± 7	86 ± 7	96 ± 7	119 ± 11	134 ± 11
			50	73 ± 8	92 ± 9	102 ± 8	128 ± 13	144 ± 13
			100	79 ± 9	98 ± 10	108 ± 10	137 ± 15	153 ± 15
Max. Ppt. Recorded (mm) (yr of occur.)				53 [74]	80 [74]	96 [74]	123 [74]	140 [74]
Probable Max. Ppt. possible				236	274	277	390	417
Sewall M.I.	9	50%	2	48 ± 1	67 ± 3	82 ± 5	89 ± 5	96 ± 5
105PA91			5	54 ± 2	81 ± 6	103 ± 8	112 ± 9	116 ± 8
3 m			10	57 ± 3	91 ± 7	118 ± 11	127 ± 12	129 ± 11
			25	62 ± 4	103 ± 10	136 ± 15	146 ± 16	145 ± 14
			50	66 ± 5	111 ± 12	149 ± 18	160 ± 20	158 ± 17
			100	70 ± 6	120 ± 14	162 ± 21	174 ± 23	170 ± 20
Max. Ppt. Recorded (mm) (yr of occur.)				63 [74]	110 [74]	127 [74]	134 [80]	140 [80]
Probable Max. Ppt. possible				170	357	526	562	508
Masset	64	50%	2	47 ± 1	59 ± 1	69 ± 1	79 ± 1	87 ± 2
1054920			5	59 ± 2	72 ± 2	84 ± 2	95 ± 2	105 ± 3
3 m			10	66 ± 2	81 ± 3	94 ± 3	105 ± 3	116 ± 3
			25	76 ± 3	93 ± 4	107 ± 4	119 ± 4	131 ± 5
			50	83 ± 4	101 ± 4	116 ± 5	129 ± 5	141 ± 6
			100	90 ± 4	110 ± 5	125 ± 6	139 ± 6	152 ± 6
Max. Ppt. Recorded (mm) (yr of occur.)				76[1898]	114[1898]	119[1898]	127[1898]	135 [04]
Probable Max. Ppt. possible				270	329	367	400	433
Masset CFS	8	50%	2	63 ± 7	74 ± 8	82 ± 9	94 ± 9	111 ± 9
10549BN			5	90 ± 11	105 ± 13	117 ± 15	129 ± 15	149 ± 16
12 m			10	108 ± 15	126 ± 18	141 ± 20	152 ± 20	174 ± 21
			25	130 ± 20	153 ± 24	170 ± 27	181 ± 26	206 ± 29
			50	147 ± 24	172 ± 29	192 ± 32	203 ± 32	230 ± 35
			100	163 ± 28	192 ± 33	214 ± 37	224 ± 37	253 ± 40
Max. Ppt. Recorded (mm) (yr of occur.)				120 [73]	150 [73]	173 [73]	182 [73]	212 [73]
Probable Max. Ppt. possible				597	719	812	818	898
Langara	47	50%	2	53 ± 1	69 ± 2	81 ± 2	92 ± 2	101 ± 2
1054500			5	64 ± 2	86 ± 3	99 ± 3	110 ± 3	119 ± 3
41 m			10	72 ± 3	96 ± 4	110 ± 4	121 ± 4	131 ± 4
			25	82 ± 4	110 ± 5	125 ± 5	136 ± 6	146 ± 6
			50	89 ± 4	120 ± 6	135 ± 6	147 ± 7	157 ± 7
			100	96 ± 5	130 ± 7	146 ± 8	158 ± 8	168 ± 8
Max. Ppt. Recorded (mm) (yr of occur.)				88 [69]	116 [69]	132 [57]	140 [57]	149 [57]
Probable Max. Ppt. possible				279	387	421	444	456

TABLE A2.2. Streamflow frequency analysis summary. All data analysis performed by Ministry of Environment Water Surveys Branch, Victoria, B.C.

STATION: Yakoun River 080A002
AREA: 477 km² YEARS OF RECORD: 24 (1962-1985)
REMARKS:

PERIOD units distribution[a]		Flow estimate	95% Confidence limits	Standard error	Flow as % of mean	Unit flow (mm)	Highest recorded flow m³s
Maximum Instantaneous	mean	345.6					736 (1963)
cm	5	437.6	357.9- 535	42.8	126	0.72	
LP	10	525.2	412.1- 669.5	62.2	152	0.92	
	20	616.9	464.5- 819.2	85.7	178	1.10	
	50	739.9	530.2-1032.5	121.4	214	1.29	
	100	840.7	581.1-1216.4	153.6	243	1.76	
Maximum Daily	mean	283.2					
cm	5	362.8	292.9- 455.5	39.3	128	0.76	612 (1983)
LN	10	444.6	342.4- 586.4	59.0	157	0.93	
	20	529.6	389.4- 733.0	83.0	187	1.11	
	50	649.1	450.5- 954.0	121.7	229	1.36	
	100	745.9	496.8-1143.5	156.3	263	1.56	
STATION: Pallant Creek 080B002							
AREA: 76.7 YEARS OF RECORD: 17 (1967-1978, 1980-1983, 1985)							
REMARKS:							
Maximum Instantaneous	mean	78.25					
cm	5	99.38	77.77-127.00	11.61	127	1.30	174.10
LP	10	119.31	88.87-160.17	16.82	152	1.56	(1978)
	20	140.05	99.34-197.44	23.14	179	1.83	
	50	167.73	112.18-250.80	32.70	214	2.19	
	100	190.34	121.96-297.06	41.30	243	2.48	
Maximum Daily	mean	53.84					
cm	5	65.68	50.29- 85.80	8.38	122	0.86	115.30
LP	10	80.34	56.54-114.16	13.59	149	1.05	(1978)
	20	96.88	62.76-149.56	20.47	180	1.26	
	50	121.67	71.04-208.41	32.40	226	1.59	
	100	143.63	77.65-265.67	44.35	267	1.87	
STATION: Premier Creek 080A003							
AREA: 0.8 YEARS OF RECORD: 14 (1971-1983, 1985)							
REMARKS:							
Maximum Instantaneous	mean	0.3570					0.617
cm	5	0.4388	0.3472-0.5738	0.0525	123		
LN	10	0.5213	0.3882-0.7300	0.0791	146		
	20	0.6070	0.4256-0.9094	0.1120	170		
	50	0.7277	0.4727-1.1867	0.1652	2.04		
	100	0.8255	0.5074-1.4296	0.2134	2.31		
Maximum Daily	mean	0.2121					0.4420
cm	5	0.2618	0.1995-0.3434	0.0333	123		
LP	10	0.3138	0.2230-0.4416	0.0506	148		
	20	0.3700	0.2455-0.5575	0.0722	174		
	50	0.4488	0.2738-0.7358	0.1069	2.12		
	100	0.5155	0.2956-0.8991	0.1397	2.43		

[a] LP = log-Pearson Type III - method of moments.
LN = log normal distribution (three parameter) - method of maximum likelihood Appendix Table 4. Storm Precipitation - Runoff Characteristics for Selected Queen Charlotte Islands Watersheds.

APPENDIX 3. Storm precipitation-runoff characteristics for selected watersheds on the Queen Charlotte Islands

TABLE A3.1. Storm precipitation-runoff characteristics for selected Queen Charlotte Islands watersheds.

A. HANGOVER CREEK (Drainage Basin Area = 20.0 km²)

Storm date	Event no.	Precip. total (mm)	Precip. intensity			Discharge instantaneous Max (m³/2)	Timing difference (day)	Stormflow volume (m³)	Storm runoff (mm)	Ratio of precip. runoff	Antecedent moisture index
		Hangover	Average (mm/day)	Maximum (mm/24 hr)	Maximum (mm/hr)						
Mar 26-29/83	H1A	28.25	9.42	23.0	5.21	0.932	0.21	207,985.8	10.4	2.75	34.87
Mar 29-30/83	H1B	4.25	4.25	4.25	1.79	0.708	0.37	75,828.1	3.8	1.12	60.82
Mar 31- Apr 2/83	H2	17.50	17.50	13.5	1.93	1.614	0.31	151,200.0	7.5	2.33	62.21
Apr 4-5/83	H3A	21.25	10.63	18.5	1.75	3.319	0.22	203,657.1	10.1	2.10	70.62
Apr 5-6/83	H3B	22.00	11.00	17.75	1.12	5.472	-0.43	259,200.0	12.8	1.72	85.54
Apr 7-8/83	H3C	13.00	6.50	8.25	0.14	1.667	0.35	49,371.4	2.4	5.42	87.59
May 14-16/83	H4	14.50	7.25	9.50	1.15	0.544	0.20	26,791.8	1.3	11.15	43.10
May 17-19/83	H5	35.75	10.13	18.50	3.13	0.808	1.68	59,165.2	2.9	12.33	65.97
May 19-20/83	H6	20.25	10.13	14.50	1.91	2.098	0.38	129,493.7	6.4	3.16	67.71
Average		**19.36**	**9.84**	**14.19**	**2.01**	**1.91**	**0.37**	**129,188.12**	**6.40**	**4.68**	**64.27**
standard deviation		**8.92**	**3.78**	**5.96**	**1.44**	**1.59**	**0.55**	**81,966.93**	**4.80**	**4.19**	**17.25**

B. SOUTH BAY DUMP CREEK (Drainage Basin Area = 3.9 km³)

Storm date	Event no.	Precip. total (mm)		Precip. intensity			Discharge instantaneous Max (m³/s)	Timing difference		Stormflow volume (mm)	Storm runoff (mm)	Ratio of precip. runoff	Antecedent moisture index
		SBD Lower	SBD Upper	Average (mm/day)	Maximum (mm/24 hr)	Maximum (mm/hr)		Lower	Upper				
Jun 4-6/83	S7	9.50	14.50	4.75	9.50	0.52	0.147	0.41	0.41	2,764.8	0.7	13.57	41.33
Jun 9-12/83	S8	20.75	24.75	6.92	14.75	1.85	0.185	0.0	0.06	11,059.2	2.8	7.41	52.04
Jun 16-18/83	S9	26.75	30.75	8.92	12.50	0.84	0.239	1.08	0.29	15,731.5	4.0	6.69	58.94
Jul 7-8/83	S10	15.25		15.25	10.75	3.13	0.163	0.54		7,474.0	1.9	8.03	54.02
Jul 12-13/83	S11A	28.00		9.33	19.5	3.85	0.340	0.18		27,504.5	7.1	3.94	59.32
Jul 13-14/83	S11B	17.00		8.50			0.366	0.49		10,762.6	2.7	6.30	75.94
Average		**17.38**		**8.95**	**13.40**	**2.04**	**0.223**	**0.450**	**0.253**	**12,549.43**	**3.2**	**7.66**	**56.93**
standard deviation		**5.86**		**3.52**	**3.94**	**1.44**	**0.119**	**0.370**		**8,493.44**	**2.2**	**3.22**	**11.37**

APPENDIX 3. Continued

TABLE A3.1. Continued

C. MILLER CREEK (Drainage Basin Area = 23.5 km²)

Storm date	Event no.	Precip. total (mm)		Precip. intensity			Discharge instantaneous Max (m³/s)	Timing difference		Stormflow volume (mm)	Storm runoff (mm)	Ratio of precip. runoff	Antecedent moisture index
		SBD Lower	SBD Upper	Average (mm/day)	Maximum (mm/24 hr)	Maximum (mm/hr)		Lower	Upper				
Dec 10-12/83	M12	35.0	46.0	23.0	23.0	3.75	10.207	1.29	1.69	546,451.6	23.3	1.97	34.87
Jan 20-21/84	M13	3.0	2.0	3.0	3.0	2.79	0.407	0.63	0.63	25,316.3	1.1	1.82	37.64
Jan 21-22/84	M14	6.0	6.0	6.0	6.0	1.32	1.403	0.59	0.43	98,452.3	4.2	1.42	42.67
Jan 22-23/84	M15	6.0	6.0	6.0	6.0	1.09	4.937	0.23	0.0	206,749.8	8.8	0.68	47.89
Jan 24-25/84	M16	5.0	9.0	5.0	9.0	0.63	2.364	0.0	0.0	94,232.9	4.0	2.25	54.41
Jan 25-26/84	M17	22.0	37.0	34.0	34.0	6.48	15.839	0.10	0.0	921,600.0	39.2	0.94	54.46
Average		**12.83**	**17.67**	**13.33**	**13.50**	**2.68**	**5.860**	**0.47**	**0.46**	**315,467.15**	**13.43**	**1.51**	**45.32**
standard deviation		**12.86**	**18.81**	**13.69**	**12.28**	**2.20**	**6.019**	**0.48**	**0.66**	**350,085.09**	**14.89**	**0.61**	**8.34**

D. PALLANT CREEK (Drainage Basin Area = 76.7 km²)

Storm date	Event no.	Precip. total (mm)			Precip. intensity			Discharge daily Max (m³/s)	Timing difference			Stormflow volume (m³)	Storm runoff (mm)	Ratio of precip. runoff	Antecedent moisture index
		Pallant*	Sewell In.	Tasu	Average (mm/day)	Maximum (mm/24 hr)	Maximum (mm/hr)		P	S	T				
Mar 26-28/83	P1	19.6	87.0	81.4	4.90	6.4	--	5.47	2	1	0	1,028,534.7	13.4	1.46	36.13
Mar 29- Apr 5/83	P2	88.4	127.6	72.6	17.68	23.6	--	10.4	3	1	5	5,108,389.0	66.6	1.33	51.84
Apr 5-8/83	P3	53.0	98.9	175.9	17.67	21.8	--	12.6	0	0	2	3,839,862.9	50.1	1.06	110.59
May 14/83	P4	13.6	4.5	2.4	13.60	13.6	--	1.52	1	1	1	17,335.5	0.2	68.0	48.00
May 17/83	P5	6.6	22.6	20.0	6.60	6.6	--	1.82	1	1	1	52,006.4	0.7	9.43	51.94
May 19-21/83	P6	6.8	27.7	16.2	6.80	6.8	--	3.30	1	1	1	381,380.4	5.0	1.36	48.24
Jun 4-5/83	P7	16.8	--	--	8.40	7.8	--	1.66	1	-	-	73,846.2	1.0	16.8	41.52
Jun 8-9/83	P8	19.2	--	--	6.40	5.3	--	2.09	1	-	-	110,769.2	1.4	13.7	52.39
Jun 15-17/83	P9	52.0	--	--	13.00	22.2	--	7.39	1	-	-	2,289,230.8	29.8	1.7	56.24
Jul 7-8/83	P10	17.0	33.8	25.0	8.50	8.8	--	2.67	1	1	1	117,169.0	1.5	11.3	72.87
Jul 10-11/83	P11	23.2	43.0	62.9	11.60	11.2	--	3.51	0	1	0	351,506.9	4.6	5.0	74.29
Mar 7-15/83	P101	121.8	226.8	155.2	20.30	30.0	--	12.4	4	4	4	6,445,484.1	84.0	1.5	35.16
May 3-4/83	P104	8.4	8.8	31.2	8.40	6.4	--	2.42	1	2	1	52,006.4	0.7	12.0	35.87
Jul 29- Aug 3/83	P105	82.4	118.0	160.4	16.48	32.0	--	11.3	1	1	2	3,661,640.8	47.8	1.7	48.24
May 24-25/83	P110	12.0	11.4	55	12.00	12.0	--	2.49	1	1	0	34,670.2	0.5	24.0	52.13
Average		**36.05**	**--**	**--**	**11.49**	**14.30**	**--**	**5.403**	**1.3**	**1.25**	**1.5**	**1,502,354.25**	**20.49**	**11.36**	**54.36**
standard deviation		**35.66**	**--**	**--**	**4.85**	**9.16**	**--**	**4.228**	**1.0**			**2,195,514.72**	**28.17**	**17.19**	**19.36**

* Pallant Hatchery (AES Station)

APPENDIX 3. Continued

TABLE A3.1. Continued

F. YAKOUN RIVER (Drainage Basin Area = 477 km²)

Storm date	Event no.	Precip. total (mm)			Precip. intensity			Discharge daily	Timing difference			Stormflow volume	Storm runoff	Ratio of precip.	Antecedent moisture
		Sewell Masset	Langara	Tow-Hill	Average (mm/day)	Maximum (mm/24 hr)	Maximum (mm/hr)	Max (m³/s)	SW	S	TH	(m³)	(mm)	runoff	index
Mar 26-29/83	Y1	33.4	19.0	52.8	11.13	23.4	--	27.7	1	0	1	6,037,267.1	12.7	2.63	35.64
Mar 29- Apr 2/83	Y2	38.0	29.1	58.6	9.50	16.6	--	46.9	2	3	0	13,448,607.5	28.2	1.35	62.97
Apr 5-7/83	Y3	36.0	39.5	36.9	12.0	12.0	--	42.7	0	2	1	11,944,700.5	25.0	1.44	77.85
May 17/83	Y4/Y5	3.2	7.8	5.8	3.2	3.2	--	3.87	1	1	0	42,270.1	0.1	32.00	58.12
May 19-22/83	Y6	9.2	39.2	20.6	3.07	3.6	--	7.49	3	3	3	887,671.2	1.9	4.84	49.23
Jun 3-5/83	Y7	6.8	--	--	3.4	3.4	--	4.40	2	-	-	62,210.2	0.1	68.00	41.06
Jun 11-12/83	Y8	13.8	--	--	4.6	6.0	--	4.86	5	-	-	248,840.8	0.5	27.60	52.55
Jun 16-18/83	Y9	25.6	--	--	8.53	9.2	--	24.5	4	-	-	5,412,287.8	11.3	2.27	51.99
Jul 3-7/83	Y10	28.2	20.5	14.4	7.05	8.6	--	17.2	3	2	3	2,931,428.6	6.1	4.62	54.90
Jul 13-14/83	Y11	20.8	26.5	39.9	6.93	6.93	--	15.3	5	5	2	1,465,714.3	3.1	6.71	66.12
Jan 22-23/84	Y14	21.4	40.6	18.2	7.13	9.20	--	88.5	2	2	2	13,001,605.1	27.3	0.78	40.47
Jan 26-27/84	Y17	64.0	58.8	33.2	21.33	37.8	--	31.0	2	1	2	56,340,288.9	118.1	0.54	69.60
Mar 8-10/83	Y101A	30.2	24.6	45.3	15.10	19.0	--	36.1	1	0	1	10,732,919.3	22.5	1.34	38.63
Mar 12-15/83	Y101B	21.2	18.5	19.4	10.60	14.4	--	53.9	2	3	2	14,086,956.5	29.5	0.72	62.00
Jan 3-5/84	Y102A	11.8	25.8	13.9	5.90	6.4	--	175.	2	1	1	19,069,020.0	40.0	0.30	62.54
Jan 8-9/84	Y102B	39.0	21.2	39.2	19.50	17.6	--	109.	1	0	2	12,134,831.5	25.4	1.54	64.39
Sep 9-11/83	Y103A	31.4	11.6	33.3	15.70	19.2	--	58.3	2	1	2	10,032,786.89	21.0	1.50	68.16
Sep 14-16/83	Y103B	53.4	28.1	46.2	17.80	31.4	--	46.8	3	2	3	9,442,623.0	19.8	2.70	81.98
May 5-10/83	Y104	49.9	70.3	30.0	9.98	14.0	--	5.80	2	5	3	803,131.2	1.7	29.35	38.29
Nov 11-13/83	Y106	27.4	19.1	44.7	9.13	12.8	--	88.2	2	1	2	13,200,000.0	27.7	0.99	77.63
Jul 24-26/83	Y107	18.6	23.5	8.1	6.20	12.0	--	100.0	3	2	4	26,110,895.9	54.7	0.34	67.24
May 24-27/83	Y110	12.8	16.4	14.9	4.27	4.8	--	5.2	0	2	0	138,680.8	0.3	42.67	43.17
Average		**27.10**	**--**	**--**	**9.64**	**13.25**	**--**	**57.81**	**2.2**	**1.89**	**1.79**	**10,344,306.0**	**21.68**	**10.65**	**57.47**
standard deviation		**15.56**	**--**	**--**	**5.35**	**8.99**	**--**	**71.25**	**1.3**	**-**	**-**	**12,461,501.2**	**26.12**	**17.89**	**13.94**

APPENDIX 3. Continued

TABLE A3.1. Continued

E. PREMIER CREEK (Drainage Basin Area = 0.8 km²)

Storm date	Event no.	Precip. total (mm) Sandspit	Precip. intensity Average	Maximum (mm/24 hr)	Maximum (mm/hr)	Discharge instantaneous Max (m³/s)	Timing difference (day)	Stormflow volume (m³)	Storm runoff (mm)	Ratio of precip. runoff	Antecedent moisture index
Mar 26-27/83	PR1	32.2	32.2	32.2	--	0.013	1	1,086.5	1.4	23.00	35.36
Mar 30- Apr 2/83	PR2	54.2	27.1	25.3	--	0.017	0	1,841.3	2.3	23.57	81.48
Apr 5-7/83	PR3	31.6	7.9	7.9	--	0.018	1	2,586.6	3.2	9.88	93.04
May 13-14/83	PR4	17.2	17.2	17.2	--	0.003	1	128.1	0.2	86.00	52.04
Jun 3-5/83	PR7	14.1	7.05	7.05	--	0.002	1	231.4	0.3	47.00	40.42
Jun 9-11/83	PR8	19.0	9.50	9.50	--	0.002	1	231.4	0.3	63.33	48.41
Jun 16-17/83	PR9	31.2	10.40	12.90	--	0.015	1	1,851.4	2.3	13.57	54.61
Jul 4-7/83	PR10	37.5	18.75	18.75	--	0.013	0	4,437.9	5.5	6.82	59.13
Jul 12-13/83	PR11	34.2	11.40	17.20	--	0.010	0	1,525.5	1.9	18.00	65.04
Dec 7-9/83	PR12A	16.0	8.0	11.60	--	0.011	1	1,213.5	1.5	10.67	35.81
Dec 10-12/83	PR12B	39.7	19.85	19.85	--	0.032	0	4,507.2	5.6	7.09	50.47
Jan 21-22/84	PR14	28.7	9.57	17.8	--	0.023	3	5,058.5	6.3	4.56	36.54
Jan 25-26/84	PR17	47.2	23.6	39.5	--	0.202	0	22,763.5	28.5	1.66	62.60
Mar 7-9/83	PR101A	56.6	18.87	41.5	--	0.020	0	4,998.0	6.2	9.13	35.01
Mar 11-13/83	PR101B	30.2	10.07	19.40	--	0.042	0	4,346.1	5.4	5.59	81.86
Jan 6-7/84	PR102A	25.7	25.70	25.70	--	0.068	0	5,690.9	7.1	3.62	80.16
Jan 8-9/84	PR102B	43.2	21.60	39.0	--	0.073	0	5,058.5	6.3	6.86	96.26
May 5-7/84	PR104	29.2	9.73	11.00	--	0.004	0	142.4	0.2	146.00	38.76
Jul 29- Aug 2/83	PR105	80.3	16.06	41.0	--	0.111	0	14,470.7	18.1	4.44	53.52
Jul 23-26/83	PR110	10.6	5.30	11.7	--	0.005	3	529.0	0.7	15.14	52.11
Average		**33.88**	**15.49**	**21.30**	**--**	**0.034**	**0.6**	**4,134.92**	**5.2**	**25.297**	**57.63**
standard deviation		**16.70**	**7.71**	**11.56**	**--**	**0.049**	**0.9**	**5,486.73**	**6.9**	**35.896**	**19.60**

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